PROCEEDINGS

OF

THE ROYAL SOCIETY

OF

EDINBURGH.

VOL. XVIII.

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CONTENTS.

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OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XVIII. 1890–91.

THE 108TH SESSION.

GENERAL STATUTORY MEETING.

Monday, 24th November 1890.

The following Council were elected:—

President.

SIR DOUGLAS MACLAGAN, M.D., F.R.C.P.E.

Vice-Presidents.

The Hon. Lord MACLAREN, LL.D. F.R.A.S.
Rev. Professor FLINT, D.D.
Professor CHRYSTAL, LL.D.
THOMAS MUIR, Esq., LL.D.
Sir ARTHUR MITCHELL, K.C.B., LL.D.
A. FORBES IRVINE, Esq. of Drum, LL.D.

General Secretary—Professor TAIT.

Secretaries to Ordinary Meetings.

Professor Sir W. TURNER, LL.D., D.C.L., F.R.S.
Professor CRUM BROWN, F.R.S.

Treasurer—ADAM GILLIES SMITH, Esq., C.A.

Curator of Library and Museum—ALEXANDER BUCHAN, Esq., M.A., LL.D.

Ordinary Members of Council.

Professor ISAAC B. BALFOUR, F.R.S.
Professor EWING, F.R.S.
Professor JACK, LL.D.
Professor JAMES GEIKIE, LL.D. F.R.S.
Professor W. H. PERKIN, D.Sc., F.R.S.
A. BEATSON BELL, Esq., Advocate.
The Rt. Hon. Lord KINGSBURGH, C.B., LL.D., F.R.S.
JOHN MURRAY, Esq., LL.D.
ALEXANDER BRUCE, M.A., M.D.
Dr R. H. TRAQUAIR, F.R.S.
Dr BYROM BRAMWELL, F.R.C.P.E.
Professor COPELAND, Astronomer-Royal for Scotland.

By a Resolution of the Society (19th January 1880), the following Hon. Vice-Presidents, having filled the office of President, are also Members of the Council:—

HIS GRACE THE DUKE OF ARGYLL, K.G., K.T., LL.D., D.C.L.
THE RIGHT HON. LORD MONCREIFF of Tulliebole, LL.D.
SIR WILLIAM THOMSON, LL.D., D.C.L., P.R.S., Foreign Associate of the Institute of France.

PROFESSOR SIR DOUGLAS MACLAGAN, President, in the Chair.

Chairman's Opening Address.

(Read December 1, 1890.)

My duty this evening is to give the usual Introductory Address at the opening of a new Session, this which commences this evening being the Society's 108th.

Before doing so, however, I must try to disburden myself of a weight which has hung heavy upon me for the last few days, and consists in the difficulty, which I find to be insuperable, how to select adequate terms in which to express my sense of the honour which you have conferred upon me, in placing me in the position of your President. In my wildest dreams it never occurred to me that such an event was possible, till a short while ago when certain members of the Council hinted to me that such a step was in contemplation; and I can assure you that it was not without considerable hesitation that I acceded to the request that I should allow myself to be put in nomination. You will, I trust, believe me, when I say that this hesitation in no way arose from any want of appreciation on my part of the greatness of the honour to be conferred on me. It was exactly the contrary. What I felt, and do feel, is not for myself, but for the Royal Society. I knew that my life has been little else than that of a practitioner and teacher of medicine. However constantly I have watched with interest the progress of Science in its various departments, my studies and any little work which I have done have been chiefly with the object of keeping myself *au courant du jour* for the purpose of teaching; and as regards her real work I have been to Science, in Horatian phrase, *cultor parcus et infrequens.* I feared, therefore, that the Royal Society might suffer in its prestige by its appearing to the outer world as if it had no man of scientific repute to fill its Chair. I know, of course, that this is not the case, that there are men among you who by their published works have made for themselves a reputation that would have truly justified their elevation to the Presidentship. It did not escape the notice of the Council, and it must have occurred to all of you, that the man who stood out as the

worthiest successor to Sir William Thomson was our indefatigable General Secretary.

But Professor Tait, with that appetite for work which does not know the meaning of satiety, thought that he could be of more use to the Society in his present office than in the more dignified position of your President, and thus he sacrificed that distinction, which might be a legitimate object of ambition to any man, for the general good of us all. The Fellows of the Society will not fail to appreciate this act of self-sacrifice on his part; and will not for a moment fancy that I have less sense of the honour I now enjoy, because Professor Tait had not seen fit to accept of it.

Our learned Vice-President, Lord M'Laren, who in July last occupied this Chair at the closing meeting of the preceding Session, adverted to the loss the Society had sustained since the commencement of the Session, by the removal by death of ten of its Ordinary, and one of its Honorary, Fellows; and he mentioned in the case of several of them a few of the incidents in their respective careers by which they had made themselves honourably known. Since that address was delivered eight more of our Ordinary Fellows have died, and I wish to be allowed now briefly to say a few words regarding each of them.

Dr James Stark, who joined the Royal Society in 1850, was born in Edinburgh in 1811. He was the son of Mr John Stark, Printer, also a Fellow, and a zealous cultivator of Natural History. James Stark studied for the medical profession at the University of Edinburgh, and took the degree of M.D. in 1833. His Thesis on that occasion was on the way in which the colours of substances affected the absorption by them of odours to which they were exposed. His experiments led him to the conclusion that odours were most readily absorbed by dark surfaces; and he conjectured that perhaps contagious emanations followed a similar law, which led him to the somewhat wide induction that the established dress of the physician, the "customary suits of solemn black," were the worst adapted for his profession.

Dr James Stark is most to be remembered as a pioneer in Scotland in the cultivation of that important and fundamental branch of Sanitary Science, Vital Statistics. In 1854, shortly after the office of the Registrar-General for Scotland was established, he

was appointed to be Superintendent of Statistics; and, in fact, he organised that valuable department of the public service. He wrote much upon the subject of Vital Statistics.

In 1846 he gave an interesting report on the mortality of Edinburgh and Leith; and in 1847 published an inquiry into the sanitary state of Edinburgh, and the rate of its mortality since 1780; and in 1851 he published his Vital Statistics of Scotland. He was also a contributor to the *Transactions of the Royal Society.* No doubt his writings are now very much superseded by the subsequent works of such authors as Farre, Simon, Newsholme, and many others, but it behooves us not to forget one who led the way in our country, when Sanitary Science had not attained its present development and its strong interest for the public mind.

Ecclesiastically he was a warm and thorough adherent of the late Rev. Dr Robert Lee, and was an elder in Old Greyfriars Church.

From long-continued and depressing bad health Dr Stark retired from official duty in 1873. He thereafter lived quite in retirement, and died at Nairn on 2nd July 1890.

The Rev. James Grant, D.D., died at Edinburgh on 28th July last, in the ninety-first year of his age. Dr Grant was long a notable personality in Edinburgh. He was a son of the manse, having been born in January 1800 at Portmoak in Kinross-shire, of which parish his father was minister. The elder Dr Grant was afterwards one of the clergy of St Andrew's Church, Edinburgh, and was Moderator of the General Assembly in 1809. James Grant received his earlier education in the school of his native parish. He was afterwards a pupil of the High School of Edinburgh, subsequently went to the University, and having passed through the Arts curriculum entered the Divinity Hall, and in due time was licensed. He was, in those days of patronage, appointed in 1824 to the first charge of South Leith, he being then only twenty-four years of age. In this charge he remained till 1843, when he was appointed to the parish of St Mary's in Edinburgh, and there he remained till he resigned in 1871. He was perhaps hardly what could be called a popular preacher in the usual acceptation of that expression, but his services were always listened to with much acceptance, because his sermons, like everything which he wrote or spoke, were characterised by great elegance of diction and clearness of utterance. No man in Edinburgh could

excel, and few equal, Dr Grant in the often troublesome task of proposing or replying to a toast, and consequently he was often called on to perform such duties. A notable instance of this lives in the memory of the present writer. It was on the occasion of a dinner to Professor Syme, when, in the unexpected absence of someone who had undertaken the duty, Dr Grant was abruptly called on to propose the toast of the Royal Infirmary, which he did in such appropriate and elegant terms that his was decidedly voted to be the speech of the evening.

Besides being an earnest parish minister, and a zealous promoter of education and of all measures for improving the condition of the poor, Dr Grant took a prominent part, and had great influence, in the Councils of the Church of Scotland. Though always ready to co-operate in matters of philanthropy with the brethren of other denominations, his strong ecclesiastical conservatism led him to become a powerful opponent of those of whose Church politics he did not approve. In the stormy predisruption times, which culminated in the great secession of 1843, Dr Grant was generally to be found in the front of the battle. He sympathised with the Presbytery of Strathbogie, who set at defiance the injunctions of the General Assembly, and was along with others put under discipline; but the chief result of this was his receiving an address from the Town Council of Leith, which was signed by many, it is said by thousands, of members of the Church of Scotland, approving of his action. That he retained the esteem of the Church was evidenced in 1854 when he received, as his father had in 1809, the highest ecclesiastical distinction which could be conferred on him, in his elevation to the Moderatorship of the General Assembly.

Dr Grant received the degree of D.D. from the Presbytery of Glasgow, and in the year of his Moderatorship Oxford bestowed on him the distinction of D.C.L.

Dr Grant became a Fellow of the Royal Society in 1851. He is to be reckoned as having belonged to the class of literary Fellows, but he was for long a regular attender at the meetings when scientific subjects were under discussion; and when from his advanced age it became unsuitable for him to go out in the evening, he even during his last year made his appearance at the Extraordinary Meetings which took place in the afternoon.

Dr Grant held numerous appointments of a clerical nature. He was a member of the Ecclesiastical Commission of Edinburgh, and was its Chairman up to about six months before his death. He was in 1841 appointed Chaplain to the Highland Society, and retained that office to the last. He was an Honorary Member of the Harveian Society of Edinburgh, and was its Chaplain for fifty-five years, having been appointed in 1844. In 1888, at the 106th Festival, the Society revived the title of *Pontifex Maximus*, which had been in abeyance since the time of Dr Grant's predecessor the Rev. Dr Moodie, and conferred it on its venerable Chaplain, who had but rarely missed a meeting during his long incumbency. Dr Grant was a genial man, though with a dry manner, and was much respected and esteemed by all who knew him.

By the death of Dr James Matthews Duncan, British Medicine, especially in the departments of Obstetrics and Gynæcology, lost one of its foremost men, and a blank has been left in the ranks of the profession which will not easily be filled up.

Dr Matthews Duncan was born in Aberdeen in 1826, and in that city he received his early as well as his academic education. He graduated there as M.A. in 1843, and in 1846 he took the degree of M.D. He subsequently studied Medicine in Edinburgh, bestowing special attention on the subject of Midwifery; and thereafter he went to Paris in pursuit of further knowledge in his own special department. He was for some time a private assistant to Sir James Young Simpson, but unhappily a quarrel arose between these two distinguished men, which led to their alienation. Duncan thereafter settled in practice in Edinburgh, becoming a Fellow of the Royal College of Physicians in 1851, and two years afterwards he commenced to deliver lectures on Midwifery and the Diseases of Women and Children, which, although at first kept in the shade by the renown and name of Simpson, soon began to show enough of brilliancy to attract an earnest though not large class of students. His reputation among his professional brethren, and subsequently with the public, led to his acquiring a large and important practice; and on the illness and subsequent death of Simpson, he unquestionably stood at the head of the Obstetric Physicians of Edinburgh. This naturally led, when Simpson died, to the general belief that he would succeed him in his chair; but the fact of

his having quarrelled with Simpson had a heavy, and in many respects unjust, effect on his prospects, and he was not appointed. His failure, however, had no discouraging effect upon him, and he went on bravely and with ever-increasing success with his practice and his teaching.

In 1877 he was offered and accepted the appointment of Teacher of Midwifery in, and Obstetric Physician to, St Bartholomew's Hospital, and he accordingly removed to London, to the widespread, we may say universal, regret of his brethren not only in Edinburgh but throughout Scotland. The reputation which led to his call to London was founded, and that justly, on the number, practical value, and, above all, the scientific character of his writings. Numerous honours were bestowed upon him. He became a Fellow of the Royal College of Physicians of London; a Fellow of the Royal Societies of London and Edinburgh; LL.D. of Edinburgh and Cambridge; and an Honorary M.D. of the University of Dublin. In London he soon acquired a very large practice, having gained the confidence and esteem of the profession and the public in the English, as he had done in the Scottish, metropolis.

Duncan's writings were numerous and important, and all partook of that scientific character which was apparent in all that he did, both as an author and practitioner. Many of them were purely practical, and chiefly concern those who are engaged in the same line of practice. Beyond this large circle he is best known by his Treatises on Fecundity, Fertility, and Sterility, which have an interest not only to the practitioner but to the statistician and political economist.

What was the source of Matthews Duncan's marked professional success? It was the genuineness of his character, personal and professional. Assuredly it was from no blandishments in his bearing or demeanour, for though a perfect gentleman in the truest sense of the word, he was, as the Countess of Rousillon says in "All 's well that ends well," "an unseason'd courtier." There was a certain dryness and abruptness in his manner which at first repelled some people, but a short knowledge of him, whether as patient or casual acquaintance, showed that under this somewhat dry shell there was a soft kernel of kindness and true courtesy which made him trusted, relied on, and beloved. It was all founded

on his genuine sterling worth, so that he fully merited the encomium of the aforesaid Countess:—"His skill was almost as great as his honesty, and had it stretched so far, would have made Nature immortal, and death should have play for lack of work."

Duncan had a naturally robust constitution, but it was observed by his friends for some months before his death that his health was seriously impaired, and a general feeling was entertained that his unwearied devotion to work was at the root of this. He abandoned teaching and professional duty, and went for a short and thorough rest to Belgium, and subsequently to Baden-Baden, where he had a severe attack of angina pectoris, from which however he rallied, and had made arrangements for his return home when he died suddenly on 1st September last. He left behind him his amiable lady, and a family of five sons and four daughters.

James Matthews Duncan will long be remembered by his professional brethren, and those who benefited by his skill, as a true-hearted friend and adviser, an unobtrusively pious Christian, and a genuine sample of that honest man who is the noblest work of God.

David Milne Home of Milne-Graden was born in 1805. His father was Admiral Sir David Milne, his brother being Admiral of the Fleet Sir Alexander Milne. He assumed the surname of Home on his marriage in 1832 with Miss Home of Paxton, in Berwickshire. He devoted himself to the study of Law, entered the Faculty of Advocates in 1826, and at the time of his death was the second oldest member of that learned body. In 1844 he was Senior Advocate-Depute, but did not continue to practise at the bar after he succeeded to the family estates. He betook himself to country life, but did not confine himself to the management and enjoyment of his property, but devoted himself to Science, for which he had manifested a strong inclination from his boyhood. He became a Fellow of the Royal Society of Edinburgh in 1828, and was for a long time a Vice-President and active member of the Council. He was Vice-President of the Royal Scottish Geographical Society, the Meteorological Society of Scotland, and the Geological Society of Scotland, of which he was elected President in 1874. This office he held at the period of his death. In 1870 the University of Edinburgh, in consideration of his scientific attainments, conferred on him the degree of LL.D.

His favourite departments of Science were Meteorology and more especially Geology, for although his first published paper was an essay on Comets, it is by his geological writings that he is best known. Our *Transactions* bear abundant evidence of his activity and industry as a geologist. In the 14th volume is to be found a series of papers "On the Mid-Lothian and East Lothian Coalfields," which attracted much attention at the time; and in that same volume there are two other papers, one on the "Depletion or Drying-up of the Rivers Teviot, Nith, and Clyde," the other on "Two Storms which Swept over the British Islands," both of which events occurred in November 1838. In the 15th volume of our *Transactions* appeared an account of the "Geology of Roxburghshire;" and in the 16th volume a paper "On the Parallel Roads of Lochaber," which is doubly interesting as being of a controversial nature, his antagonist being so redoubtable a scientific warrior as Charles Darwin, who, however, with the courtesy of a true knight, subsequently acknowledged himself to have been worsted in the encounter.

To the 25th volume of the *Transactions*, published in 1869, Milne Home contributed a paper "On the Origin of the Boulder Clay." This subject had always a special interest for him, and a goodly boulder anywhere excited in him an enthusiasm which neither advanced age nor failing health could check. He was appointed by the Society Convener of the Boulder Committee which was established in 1871; and under his supervision the Committee published ten valuable Reports, which are contained in the Society's *Proceedings*. These are only part of Mr Milne Home's contributions to Science. He was the author of many other papers both within and without the domain of Geology, and of two books, one on the "Estuary of the Firth of Forth and Adjoining Districts viewed Geologically," and the other on "Ancient Water-lines."

Mr Milne Home had within the last two years a severe and protracted illness, which carried him off on the 19th September 1890. He leaves us an admirable example of what may be done for Science by a country gentleman possessed of means and leisure, but animated by the laudable ambition to extend the knowledge of his fellow-men.

The Hon. Lord Lee (Robert Lee) was born in 1830, and was a son of the Rev. John Lee, D.D., Principal of the University of

Edinburgh. He devoted himself to the study of Law, and became a Member of the Faculty of Advocates in 1853. He had a fair, but not what is regarded as a large, practice at the Bar; but he was noted for his earnest devotion to his duties both as Barrister and subsequently as a Judge. He was made an Advocate-Depute in 1867, and held that office till he was appointed Sheriff of Stirling and Dumbarton in 1875, from which he was transferred to the more important Sheriffship of Perthshire. He was for many years Procurator of the Church of Scotland, and performed the duties of that legal office with much earnestness and general acceptance. He was raised to the Bench in 1880. He formed his opinions slowly, deliberately, and conscientiously, and was very tenacious of them when once formed, his firmness in this respect being by some cynical people called obstinacy. His leading characteristics were his earnestness of purpose, and his unwearied patience. He became a Fellow of the Royal Society in 1872, but did not take any special part in its proceedings. In private life he was much esteemed, and had a considerable fund of genuine humour. Robert Lee was for a long time in delicate health, suffering for many years from bronchial asthma. He had been enjoying in Ireland a holiday, which he had intended extending to St Andrews, but a sharp inflammatory attack came on, and proved fatal on 11th October 1890. He left a widow, daughter of the late Dr Borthwick of Edinburgh, and a family of three sons and three daughters.

Mr DAVID GRIEVE was educated at the University of Edinburgh, and became a solicitor-at-law. He subsequently entered H.M. Customs, and was collector at Banff, Great Grimsby, and Dover. He took much interest in Natural Science, particularly in Geology and Anthropology. He made a large collection of fossils. He was several times President of the Royal Physical Society, and was elected a Fellow of this Society in 1872. He died in June of last year.

As Medical Science sustained a great loss in Matthews Duncan, so did Classical Literature in the person of Professor WILLIAM YOUNG SELLAR. There was a considerable parallelism between the two men in their earnest devotion to work, in their clearness of judgment, and, above all, in their contempt for everything that was not in accordance with the highest ethical standards.

Professor Sellar was the son of the late Mr Patrick Sellar, and was

born at Morvich, in Sutherlandshire, in 1825. From his earliest years he was a classical scholar. His earlier education was got at the Edinburgh Academy under Archdeacon Williams. He went to Glasgow University at the early age of fourteen, carrying with him from the Academy so much of classical lore as to lead him to go at once into the Senior University Classes, whence he came forth with highest honours in Greek and Latin, and much distinction in the other classes. He was elected to a scholarship at Balliol College, Oxford, in 1843. In 1847 he obtained first-class honours in *Literæ humaniores*, and in 1850 was made a Fellow of Oriel. He had for contemporaries a brilliant assemblage of men more or less connected with Scotland, two of them, Shairp and Grant, subsequently becoming Principals of Scottish Universities. After acting as Assistant to the Professor of Humanity in Glasgow, and to the Professor of Greek in St Andrews, he was in 1859 elected to the Greek Chair in the latter University, and from this he was transferred to the Latin Chair in Edinburgh in 1863. Honours flowed in upon him. He received the degree of LL.D. both from St Andrews and Dublin, and was admitted to the membership of the Athenæum Club, without ballot, "as being of distinguished eminence in literature." Though his first published writing was an article on Thucydides, which appeared in the Oxford Essays, the works by which he is best known, and for which he is everywhere appreciated, were in connection with Latin literature. His volumes on the "Roman Poets of the Republic," and the "Roman Poets of the Augustan Age," hold a foremost place in modern classical literature, have passed through several editions, and are valued by all scholars, British and Continental. His teaching as a professor, though his minute scholarship was profound, was characterised by great breadth; and he imparted to his students a large share of that with which he was himself imbued, the insight which the study of the Roman poets gives into the political, social, and moral characteristics of the Romans.

He had been working for some time at a new volume of the Roman poets, which would embrace studies of Horace, Ovid, Propertius, Tibullus, and Martial, and which a few weeks more of work would have completed. But unhappily this was not to be, for an unexpected attack of hepatic disease proved fatal to him at his country residence in Kirkcudbrightshire on 12th October. It is to

be hoped that a volume so far advanced may see the light, as it will assuredly give to the world another brilliant picture of Roman life, though wanting the finishing touches of the master.

By the death of Sellar classical literature has sustained a severe loss, the University of Edinburgh has a Chair vacant, which he had ably filled for twenty-seven years, and his colleagues and all who knew him have to mourn their bereavement of a genial friend and accomplished gentleman.

Mr Alexander Yule Fraser was born near Perth. He was educated at the University of Aberdeen, where he distinguished himself specially in the departments of Mathematics and Physics, though he did not neglect the other subjects of the Arts course.

After graduating with first-class honours in Mathematics and Physics, he was appointed second mathematical master in George Watson's College, Edinburgh. When George Heriot's Hospital was opened as a day-school, Mr Fraser was entrusted with the charge of the Mathematical and Physical Departments; and it is not too much to say that not a little of the success of this school is due to the energy with which he threw himself into the work of his department. He spared no pains in providing for the due equipment of the Physical Laboratory, and in preparing courses of Practical Geometry and Experimental Physics suitable for boys. Just a little over a year ago, Mr Fraser was appointed Headmaster of Allan Glen's Institution, Glasgow, one of the most important technical schools in the country; and it was hoped that he would now have an opportunity of displaying to the full his special qualifications for a post of this nature. But he had been at work little more than two months when he was attacked with pleurisy and threatened consumption, and felt compelled to tender his resignation. The governors of the school, however, were so much impressed with the value of his work that they declined to accept his resignation, and granted him instead nine months' leave of absence, in the hope that a change of climate, and a complete rest for this period, would restore him to health. In search of health Mr Fraser visited South Africa, where he resided for several months. About three months ago he returned to this country, and resumed his duties at the beginning of the present Session. He soon found, however, that his health was again giving way, and he had to resign his position

finally. He had made up his mind to return to South Africa with the purpose of residing there permanently, when he caught a chill, which led to acute inflammation; and to this he succumbed on the 9th of November last, at the early age of thirty-three.

One of the objects that absorbed a very large amount of Mr Fraser's attention during the last eight years of his life was the Edinburgh Mathematical Society. This Society may be said to owe its existence mainly to him. The idea of starting such a Society originated with him; and as its Secretary during the first four or five years of its existence, he had all the trouble connected with the arrangements necessary to put such an institution upon a firm basis. This Society is now in its 9th Session, has about 150 members, and publishes a volume of *Proceedings* annually. Mr Fraser has made contributions to nearly every volume of the *Proceedings.* A subject that interested him from the time of his student days was the history of the controversy on the foundations of the Differential Calculus. Till within three weeks of his death he had hoped to be able to give an address to the Mathematical Society on this subject at the meeting held on the 14th of November. It is still hoped that it may be possible to put the notes he left on this subject into a form that will prove useful. Mr Fraser also contributed several articles to the edition of *Chambers's Encyclopædia* which is now being issued. The mathematicians that interested him most were De Morgan and Clifford. Of Clifford's book *On the Common Sense of the Exact Sciences*, he wrote a review which appeared in the pages of the *Academy.* In poetry Mr Fraser had a great fondness for the works of Matthew Arnold.

Mr Fraser was remarkable, among other things, for the activity of his intellect, an intellect that could never be idle; and for the energy with which he devoted himself to any work he undertook. His friends always found a talk with him to have a stimulating effect, and many will find in the future want of this stimulus a loss which it will not be easy to make good.

I had intended to have said a few words to the Society, chiefly by way of contrast, regarding the various distinguished men who have occupied this Chair since its foundation in 1783, but I have already too much tried your patience, and have exceeded the time which I had assigned to myself for the delivery of this address.

I wish to allude to only two of the previous Presidents of the Society.

I need not say that when I mention the name of Sir Walter Scott, I am not presumptuous enough to make any remarks about him at any time or anywhere, but especially here, and on Scottish ground. I merely desire to state to you an interesting circumstance which is perhaps new to most of you, and which does not appear in that interesting Journal which has been so ably edited and published by Mr David Douglas of this city. It is that the Council has recently made a valuable addition to the Society's collection of manuscripts by securing a holograph letter of Sir Walter's, in which he tenders his resignation of the Presidency of the Society. It appears that in the latter part of the year 1830, Sir Walter, with the view of residing constantly at Abbotsford, contemplated renouncing all associations which would detain him in Edinburgh. In a letter to his friend, Mr James Skene, dated Abbotsford, 18th September 1830, he says :—

"It is time to think what is to be done about the Royal Society, as the time of my retirement draws nigh, and I am determined at whatever loss not to drag out the last sands of my life in that sand cart of a place the Parliament House. This is, however, a subject for future consideration, as I have not breathed a syllable about resigning the Chair to anyone, but it must soon follow as matter of course."

On the 18th of the following month he wrote the letter to which I have referred as having now come into the possession of the Society. It is as follows :—

"I have the honour to acquaint you for the information of the Royal Society, its Council, and Members, that being conscious of the entire want of that scientific knowledge which would be the most fit qualification for supporting the honour of their body, I have hitherto endeavoured to show my sense of the distinguished honour of President to which their pleasure has raised me by regular attendance upon the meetings of the Society and duties of the office. As I am now retired from Edinburgh to live almost entirely at this place, which must necessarily prevent my discharging the efficient duty of President of the Society, and prevent almost entirely my

present attendance, I think it due to the Royal Society to resign the high honour which they have conferred on me with heartfelt thanks and best wishes for the prosperity of the Institution.

"I remain with sincere regard,

"Sir,

"Your most obedient Servant,

"WALTER SCOTT."

"ABBOTSFORD, 18*th October* 1830."

"John Robison, Esq., Secretary to the
"Royal Society of Edinburgh."

This letter was submitted to the Council at a meeting held on the 8th of November 1830. The following is the minute regarding it:—

"Read a letter from Sir Walter Scott intimating his intention of residing in the country, and proposing on that account that he should cease to hold the office of President of the Society.

"The Council having considered his letter were unanimously of opinion, that although they could not under the circumstances hope to have the benefit of Sir Walter Scott's frequent presence amongst them, yet that it was very desirable for the interests and reputation of the Society that he should still continue at their head. The meeting therefore instructed the Secretary to write on their behalf to Sir Walter Scott, and to request that he would again permit them to propose his name as on former occasions of election."

In consequence of his resignation not being accepted, Sir Walter continued to be President till his death.

The other President whom I desire to name is the distinguished gentleman who has been my immediate predecessor. Of Sir William Thomson, who held the post of President for the full term of five years (1873–1878), and who has now, at his own request, been permitted to retire before the completion of a second term of office, it is perhaps sufficient to say that he leaves our Chair only in order that he may be enabled to assume the corresponding post in the Royal Society, London.

His position is practically unique, for, while second to none in the ranks of pure Science, he is absolutely without a concurrent in

the technical applications of some of its most recondite principles. The grandest works of the engineer are usually based on very simple scientific elements, and his skill is shown mainly in new and bold combinations of familiar properties. Thomson has done much splendid work in this direction also—witness his galvanometers and electrometers, his siphon-recorder, and his harmonic analyser. But it will never be forgotten that it was he who so applied the profound analysis of Fourier as to render rapid signalling possible through a submarine cable—thus making ocean telegraphy a mercantile success—so that we owe to him one of the grandest safeguards of our empire, our practically instantaneous communication with our most distant and isolated colonies.

You have already at your election meeting expressed and recorded your thanks to Sir William Thomson for his conduct as our President. You will, I am sure, with unanimity and cordiality, express your wishes for his comfort and success in the sphere of distinction and duty to which he has been called.

Three Prizes were awarded during the past Session.

The Gunning Victoria Jubilee Prize for 1887–90 was presented to Professor Tait for his work in connection with the "Challenger Expedition," and his other researches in Physical Science. His contributions to Physical Science are too numerous for me to enumerate; but in reference to his "Challenger" work I may call attention to the ingenuity with which he has determined the physical properties of sea water, such as compressibility, thermal expansivity, and its temperature of maximum density for any given pressure. He has also included in his investigation the compressibilities of glass.

The Keith Prize for 1887–89 was presented to Professor Letts for his researches into the "Organic Compounds of Phosphorus." The work was difficult, and the results are of great importance. The special interest of the investigations depends on the remarkable similarities, and equally remarkable dissimilarities, shown by the corresponding compounds of phosphorus, nitrogen, and sulphur. These researches have been published in our *Transactions*.

The Neill Prize for 1886–89 was presented to Mr Robert Kidston for his "Researches in Fossil Botany." He has devoted himself to the

study of Palæophytology, and has sought to determine the affinities of palæozoic genera and species with those of existing forms. With this view he has described the fructification of a number of carboniferous ferns and lycopods. He has compared the plant remains of several British coalfields with each other, and with those of the coalfields of other countries. The most important results of his investigations have appeared in our *Transactions.*

On the Occurrence of Sulphur in Marine Muds and Nodules, and its bearing on their Mode of Formation. By J. Y. Buchanan, Esq., F.R.S.

(Read December 1, 1890.)

In the first section of the cruise of the "Challenger," that from Tenerife to Sombrero, the existence was established of deep-sea muds, perfectly free from carbonate of lime, consisting mainly of silicates mixed with ochreous material, principally hydrated oxides of iron and manganese, and of local concentrations of these materials in the form of nodules and of coatings or incrustations on dead calcareous matter. The qualitative composition of these concentrations was carefully determined, and it was particularly noted that whether in the form of nodules or of incrustations they were aggregations of the general materials of the bottom, and not concretions or coatings of pure hydrous oxides.

On the section between Bermuda and the Azores some very suggestive specimens were got from the bottom on 27th June 1873, when the ship dredged in 1675 fathoms in lat. 38° 18′ N., long. 34° 48′ W. A number of light-coloured concretions were brought up which were much perforated by worm-holes, the walls of which were all stained blackish brown. The substance of the concretions consisted of carbonate of lime and silicates, and the black lining of the holes was peroxide of manganese. The various specimens obtained on this occasion showed the deposition of oxide of manganese in various stages, from those which showed only specks or stains to those containing a considerable percentage.* The most remarkable fact, however, was the close association of the oxide of manganese, especially at its first appearance, with the work of

* They are described in my report, *Proc. Roy. Soc.*, 1876, vol. xxiv. p. 606.

annelids, and this produced a strong conviction that the occurrence of peroxide of manganese at the bottom of the sea depended in some way or other on the organic life existing there.

After this comparatively little manganese was met with, until, on approaching the south coast of Australia, a large haul was obtained from a depth of 2600 fathoms in lat. 42° 42′ S., long. 134° 10′ E. and throughout the whole of the Pacific, when the trawl was put over in water sufficiently deep and sufficiently far from land, it rarely failed to collect abundance of manganese nodules, of all shapes and sizes, and surrounding all kinds of nuclei. Concretions also were obtained from time to time, recalling those of the North Atlantic above referred to. Thus, on the plateau of the Kermadec Islands, large lumps of a tufaceous sandstone were brought up, which were much perforated by serpular borings, and these were lined with peroxide of manganese. At the first station after leaving Japan, and on the landward side of the deep gully which runs parallel with the islands, a large haul was obtained, chiefly of pumice, tuff, and volcanic mud concretions. These were much perforated by worms, and the holes were lined with black oxide of manganese. One concretion, a portion of which is on the table, was broken open in the plane of one of the worm-holes, and the worm was found dead in it.* On another portion a dead worm was found adhering, and on removing it a black stain was found below it consisting of peroxide of manganese. The connection of the peroxide of manganese with the life of these animals was very marked in this case, and continued to occupy my attention from time to time, though without arriving at any satisfactory solution, during the cruise. It must not be forgotten that an invariable feature of the nodules was that they gave off abundance of alkaline and empyreumatic-smelling water on being heated, which served further to connect them with the organic world.

After the return of the "Challenger" I did a good deal of dredging in the summers of several years (1877–1882) in the seas on the west coast of Scotland, and on the 21st September 1878 I brought up from the deepest parts of Loch Fyne (104 fathoms) a quantity of sandy mud, with large quantities of dead pecten shells, and along with them true manganese nodules, with all the outward

* The body of this worm was tested and found free from manganese.

characteristics of those from the greatest depths of the open ocean; and this similarity was maintained on chemical examination. The dredging anchor must on this occasion have been dropped in the very richest part of the deposit; for the mud, which had undergone no concentrating process, was found, on being submitted to mechanical analysis, to consist of rather over 30 per cent. of nodules.* This was a very remarkable discovery; for although peroxide of manganese was not wanting in the shallower dredgings of the "Challenger," it existed only as coatings and similar deposits and not as nodules, which were believed to be dependent for their formation on the conditions obtaining in very deep water. After this particular attention was paid to the occurrence of manganese in all dredgings, and it was found to be abundant all round our coasts as a coating on shells, and more especially as the binding and colouring matter of worm tubes; but no nodules were anywhere found except in the deep part of Loch Fyne. Some years afterwards Mr Murray found them in great abundance on the Skelmorlie Bank in the Firth of Clyde in 10 fathoms.

In the same summer of 1878 I made a number of observations in the channel off the north-east part of the Island of Arran, where the water reaches a depth of 90 fathoms. A galvanised iron bucket was used as dredge, with a weight attached behind, and one before it; so that its action was rather to skim the surface than to dig into the lower layers of the bottom. It brought up a quantity of a very fine red mud, in which manganese grains could be detected, not apparently differing from those found in oceanic red clays. In the process of levigation, when the mud was stirred up with water and the light flocculent portion poured off, the heavier portion which had settled to the bottom of the vessel had the appearance of having been cast into elongated pellets. When these were stirred up again with water they were partially broken up into flocculent matter, which was poured off, leaving again pellets as before; and this could be continued until the whole of the mud had been washed away as flocculi, produced by the breaking up of these pellets. In the case of the particular mud under description, hardly anything in the shape of sand or coarser material remained behind. The ground-fauna, chiefly ophiurids, seemed to be abundant; and the pellets

* *Nature*, 1878, vol. xviii. p. 628.

above described were the casts excreted by these creatures, which subsist on what nutriment they can pick up by triturating and passing the sand or mud through their bodies. In some of these animals the triturating apparatus takes formidable proportions, as in sea-urchins; and it is probable that the sand found at low water owes its state of comminution largely to these animals and to worms, such as the ordinary lob-worm used for bait. When examining deep-sea clays in the "Challenger" I had observed the pellet formation, without, however, being able to refer it to any probable cause. Now, however, it became probable that the same causes are at work in deep as in shallow seas, and that the matter forming the bottom of the sea is being continually passed and repassed through the bodies of the numerous tribes of animals which demonstrably subsist on the mud and its contents.

In the following season, 1879, I made an extended cruise through the greater part of the waters of the west coast of Scotland, visiting most of the deeper spots, and paying particular attention to the occurrence of coprolitic mouldings of the mud. Thus, on 16th June 1879, dredging in the deep part of the Sound of Raasay in 155 fathoms,* "a little mud came up. It was a fine gray clay, which effervesced with acids and smelled of H_2S. On washing a quantity of it there remained the coprolitic masses and very little fine sand. There appeared to be a good deal of carbonate in a very fine state of division. There were very few shell particles visible, and the effervescence of what looked like flocculent clay was not inconsiderable." At the time I explained this flocculent carbonate as having been produced out of the silicates of the mud by the ground animals forming sulphide of calcium, which was transformed into carbonate by the carbonic acid of the water. On the following day another haul was got in the same locality and with similar results; it is noted that—"Sticking to the outside of the bag were many legs of ophiurids, which will account for the coprolites." When attention had once been paid to it, the coprolitic moulding of the mud, when of a suitable consistency, was found to be practically universal round our shores.†

* From deck-book of Steam Yacht "Mallard," 1879.

† Later, in the year 1886, when in charge of the expedition to survey the Gulf of Guinea in the steamship "Buccaneer," I found the same thing practically

Shore muds, that is, the terrigenous deposits which are found all along the shores of continents, and even at great depths—generally present the characteristic appearance of a reddish surface layer, overlying a bluish substratum. This characteristic is observed in deposits even far out at sea, and, where it is not masked by large amounts of calcareous matter, is evidently due to the oxidation of the bluish ferrous salts, on their coming in contact with the sea water, which always contains dissolved oxygen.

A very remarkable example of a blue clay—for it was too tenacious to be called a mud—was obtained in the Sound of Jura, and it was particularly noticeable for the amount of sulphides which it contained, and instructive by their complete disappearance on drying. It is worthy of more particular mention.

On 6th July 1879 the anchor dredge was put over in the Sound of Jura, where a depth of 120 fathoms was marked on the chart. It did not hold, and the yacht drifted, dragging it over the ground in a northerly direction before the wind and tide. Suddenly it hooked the ground, and brought the vessel up with a great strain on the cable. In heaving up it was with difficulty that the anchor was broken out of the ground; and when it was brought to the surface the bag was full of a fine, unctuous, very tenacious blue clay, with some of the reddish-brown surface mud covering it. There were a few pieces of broken shell and rock, also smooth and rounded pebbles, which seemed to occur principally in the part separating the surface mud from the blue clay, but there was very little of this kind of matter. The whole bagful, weighing more than

universal all along the African coast, and developed in a most remarkable manner on the coast flat within a considerable radius of the mouth of the river Congo. Here it was necessary to introduce a new designation for muds, and in this district the most frequent entries in the deck-book as to the nature of the bottom are "cop. m.," meaning coprolitic mud. These so-called coprolites were almost jet black and of the size of mice droppings, and they were covered with the same substance in flocculent form, or were free from it, according to the scour of the tide in the locality. It was best developed in comparatively shallow water, and more especially in a depth of 50 fathoms, when the large ash bucket, to the use of which as a dredge I found it convenient to revert, came up full of these coprolites, without any flocculent matter whatever. All along the coast the mud of the locality was moulded in a similar way, though it was not so striking. When the course of the cruise took us across the open ocean to Ascension, and thence northwards, we were able to trace the transition of the more earthy shore coprolites into the more mineralised and glauconitic pelagic ones.

1 cwt., consisted almost entirely of homogeneous blue clay of a tenacity similar to the clay dug for brickmaking, and quite different from ordinary "blue muds." The clay was rather foul-smelling, and gave off abundance of sulphuretted hydrogen when treated with hydrochloric acid. It was so tenacious that it was impossible to break it up in water for the purpose of levigation, which is always very easily accomplished with ordinary muds. A considerable portion of it was dried and taken for analysis. It was found that, as soon as dry, not a trace of sulphide was to be found; but the mass of the clay was permeated with fine particles of oxide of iron, each of which represented a previous particle of sulphide. A specimen of this clay is on the table. The contrast between the fresh moist clay, which was thoroughly impregnated with sulphides, and the dried clay, without a trace of them, was very striking.*

The fact then had been demonstrated that the mud is being continually passed and repassed through the bodies of animals inhabiting the bottom of the sea. In doing so the mineral matter of which it consists comes in contact with the organic secretions of the animals, mixed with sea water, and is ground up along with them in the milling organs of the animals.

The Reducing Action of organic matter on sulphates has long been known, and its importance as an agent in geological metamorphosis was thoroughly recognised by Bischof.†

The effect of Trituration in promoting the chemical decomposition of silicates by water was demonstrated by Daubrée,‡ more particularly in the case of Felspar. I found the observations to hold good also for Augite. Clear crystals of this mineral from the Tristan da Cunha group, when pulverised with water in an agate mortar, rendered the water alkaline to turmeric paper.

It is evident therefore that at the bottom of the sea a number of conditions occur together, which are favourable to the production of chemical change. The ground animals, in the search of food, pass the mud through their bodies, grinding it up, and bringing it

* A condensed account of my views of the part played by the sulphates of the sea water in the production of the ochreous deposits on the bottom of the ocean, and of the carbonate of lime of the shells of the Mollusca, is published in the *Reports of the British Association* (York), 1881, p. 584.

† Bischof, *Lehrbuch der Chemischen und Physikalischen Geologie* (1863), i. 31, 358.

‡ Daubrée, *Geologie Experimentale*, i. 268.

thoroughly into contact at the moment of comminution with the sea water and the digestive secretions of the animal. The action of these secretions on the sulphates in the sea water is to produce sulphides, and the actions of the sulphides on the ochreous matter of the bottom is to produce sulphides of iron and manganese. Even if the bottom were covered with felspathic or augitic sand, the sulphides, acting on these silicates in the moment of partial decomposition, would convert the ochreous oxides by degrees into sulphides. That the volcanic material, lava, dust, scoriæ, pumice, which forms the bulk of the unaltered material of the bottom of the ocean, is so dealt with by the animals, is evident from the specimen from the Pacific on the table, which is not a singular specimen, but rather a typical one.

Having extracted what nutriment they can from the mud, the animals reject it, containing a certain proportion of sulphides of iron and manganese. These sulphides, it is well known, are exceedingly unstable in presence of water and oxygen, and if they come to lie on the surface of the mud, where they are exposed to the action of the sea water, which always contains dissolved oxygen, they must be quickly transformed into oxides. In the oxidation of ferrous sulphide by this process there is always separation of free sulphur, which, however, is to a great extent further oxidised; but it is probable that some would persist. If then the process just described represents at all what takes place in nature, we should expect to find in the ochreous deposits (the hydrous oxides of iron and manganese) some relics of their connection with the organic world. These are not wanting. All the deep-sea muds and manganese concretions, of every diversity of form, gave without exception, when freshly collected and heated in a tube over the lamp, a large quantity of ammoniacal water. It was important to see if sulphur could be detected. And here it is well to bear in mind that in the case of a "blue mud," which may contain unaltered sulphide, the sulphur found in the dried sample will come at least in part from that sulphide, and will be due to the oxidation by the atmosphere in the process of drying. In the case of an oceanic "red clay" or manganese nodule, where no blue matter is present, any sulphur which is found may be properly ascribed to oxidation on the bottom of the sea.

Acting on these considerations, in the winter of 1880–81, a number of muds and nodules were examined with a view to the detection, and if possible the estimation, of free sulphur.

Estimation of Sulphur in Muds.

A certain quantity of the clay, dried at about 80°, was put into a bottle with a known weight of chloroform. The stopper was tied down, and it was then put into a water-bath for about an hour at about the temperature of boiling chloroform (61° C.). It was then allowed to cool, filtered into a weighed fractionating flask, and washed twice with a little more chloroform. The chloroform was then distilled off, and the residue heated slightly and weighed.

The residue was treated with hot nitric and hydrochloric acids, diluted, and filtered if necessary, barium chloride solution added, allowed to stand, filtered, and the precipitate of barium sulphate weighed.

In the first few samples the barium sulphate was not weighed, but the quantity of sulphur judged by the amount of barium sulphate precipitated.

At first bisulphide of carbon was used, but it was departed from. because, although perfectly pure, and leaving no trace of sulphur on evaporation, it was thought that it would be well to use a solvent not containing any sulphur. A portion of the blue clay from the Sound of Jura, which when fresh contains much sulphide, was in the dried state tested with both solvents, with the following results.

Treatment with Bisulphide of Carbon.—A quantity of the clay was pounded and dried at about 80°. 50·00 grammes were put into a bottle with 236·0 grammes of bisulphide of carbon, and allowed to stand all night. A weighed portion of the carbon bisulphide was then taken out and put into a weighed flask, and the carbon bisulphide distilled off, and the residue weighed. 0·28 per cent. of sulphur was found in this way.

The sulphur dissolved completely in a small quantity of bisulphide. Next day another portion of carbon bisulphide was taken out and put into a weighed flask, distilled, and the residue weighed. This gave 0·33 per cent. of sulphur.

The bisulphide was tested to see whether it contained any free sulphur; it turned out to be very nearly pure.

TABLE *giving the Results of the Treatment of various Samples of Sea-Bottom with Chloroform for the Extraction of Sulphur.*

No.	Description of Sample.	Weight of Sample taken (Grammes).	Weight of Chloroform added (Grammes).	Weight of Residue (Grammes).	Per Cent. of Residue.	Weight of $BaSO_4$ (Grammes.)	Per Cent. of Sulphur.	Remarks.
		a	b	c	$d=100\frac{c}{a}$	e	$f=13{\cdot}73\frac{e}{a}$	
1	Clay (C) Sound of Jura, . . .	50·0	183·6	0·1970	0·39	...	...	Very little oil; sulphur looked very pure.
2	Manganese Nodule, 16th Sept. 1875, .	78·8	228·1	0·0232	0·029	...	...	There was a little oil.
3	" " 12th July 1875, .	77·8	232·3	0·0470	0·064	...	...	" "
4	Sound of Raasay, 1880, . . .	65·7	111·9	0·0230	0·034	...	...	A good deal of oil.
5	Loch Duich, ...	81·2	120·5	0·0298	0·036	...	...	" "
6	Loch Fyne, 104 fathoms, 1st Oct. 1878, .	117·2	138·5	0·0150	0·055	...	...	" "
7	Clay (A), Glen Sannox, 3d Oct. 1878, .	84·2	153·3	0·0318	0·038	...	...	" "
8	Red Clay Mud, 2975 fathoms, . .	78·0	156·0	0·0222	0·028	...	...	A little oil.
9	Manganese coating concretion, . .	97·5	178·2	0·0022	0·002	0·00135	0·0002	Very little oil.
10	Off Garvelloch Islands, 23d July 1881,	79·6	119·0	0·0182	0·023	0·01345	0·0023	A little oil.
11	Loch Fyne, Upper Basin, . .	78·1	140·8	0·0550	0·074	0·03945	0·01	Large amount of oil. A crystal of sulphur separated out before chloroform had distilled off.
12	Globigerina Ooze (Pacific), . .	79·5	182·3	0·0072	0·009	0·00095	0·00016	A little oil.
13	" " (Atlantic), . .	78·5	165·5	0·0250	0·032	0·00195	0·00034	Very little if any oil. Did not require to be filtered after oxidation.
14	Garvelloch Islands (siftings), . .	90·0	152·2	0·0094	0·010	0·00915	0·0014	Very little oil.
15	Off Rum, 15th Aug. 1881, . .	125·7	183·5	0·0154	0·012	0·01195	0·0013	" "
16	Blue Mud, 8th Feb. 1875, . . .	79·0	135·2	0·0086	0·011	0·01895	0·0033	Very little if any oil. Did not require to be filtered after oxidation.
17	Bottom, 410 fathoms, . . .	91·1	114·9	0·0042	0·005	0·00195	0·00029	Very little oil.
18	Diatomaceous Mud, . . .	15·6	160·0	0·0212	0·136	0·00275	0·0024	Very little if any oil. Did not require to be filtered.
19	13th March 1874, 2600 fathoms, . .	44·5	128·3	0·0090	0·020	0·00295	0·00067	Very little oil.
20	Rad. Ooze, 25th Aug. 1875, 2900 fathoms,	44·4	170·8	0·0270	0·061	0·0102	0·0031	A little oil.
21	Globigerina Ooze (Atlantic), . .	73·8	185·2	0·002	0·0026	0·0015	0·0002	Very little oil. Did not require filtering.
22	" " (Pacific), . .	70·5	185·0	0·0025	0·0035	0·0024	0·0004	" " "
23	Manganese Nodule, 16th Sept. 1875 .	58·8	128·7	0·0012	0·0020	0·0001	0·000017	Nodule dissolved with HCl in presence of $FeCl_2$ and residue treated
24	Loch Fyne, Otter House, . . .	79·8	178·1	0·0142	0·017	0·0053	0·0009	A little oil.
25	Loch Ness, off Urquhart Castle, .	75·0	150·8	0·2805	0·374	0·0292	0·00413	Much oil and solid fat.
26	Isle Oronsay, 6 fathoms, 19th July 1879,	85·4	147·5	0·0038	0·004	0·0028	0·00044	Very little oil. Did not need filtering.
27	Garroch Head, 87 fathoms, 13th June 1879,	89·2	153·5	0·0036	0·0043	0·0020	0·00032	" " "

Treatment with Chloroform.—Another 50·00 grammes of clay were treated with 183·6 grammes of chloroform. The mixture was heated for an hour on the water-bath at about the temperature of boiling chloroform (61° C.). A portion of the chloroform was then taken out, evaporated, and the residue weighed. This gave 0·39 per cent. of sulphur.

There was very little oil present in the residue, which was nearly pure sulphur.

In the first ten samples the $BaSO_4$ was not weighed, but the residue was always oxidised and the presence of sulphur proved by the formation of sulphuric acid. When sulphur was found constantly and in appreciable quantity, I then decided to weigh it, the operation being, from an analytical point of view, an advantageous one, as the sulphate of barium weighed weighs seven times more than the sulphur to be estimated. By far the largest amount of sulphur is contained in the clay from the Sound of Jura, which, in its fresh state, contained large quantities of sulphides, which were completely oxidised on drying. The 0·197 grammes of residue may be taken to be pure sulphur, which makes about 0·4 per cent. By far the greater part, if not the whole, of this sulphur was formed by oxidation during drying. Had it been possible to collect and examine separately the reddish-brown surface layer, we should, no doubt, have found very much less sulphur, but it would have been mainly due to oxidation by the oxygen of the bottom water.

The "oil," which is extracted from all the muds along with the sulphur, and which varies a good deal in quantity, is due to the animal débris intimately mixed with the mud and with the materials of the nodules, which are made up, for the most part, of the materials of the bottom.

Nos. 2 and 3.—The manganese nodules of the 12th July 1875, from the North Pacific, in lat. 37° 52′ N., long 160° 17′ W., came from a depth of 2740 fathoms, where they appear to have been exceptionally abundant. Those of the 16th September 1875 came from a locality where they were equally abundant. The water was a little shallower, being 2350 fathoms, in lat. 13° 28′ S., long. 149° 30′ W. In both the samples of these nodules examined, the weight of the residue is considerable, but as there was a little oil in both cases it is not possible to give the percentage of sulphur.

No. 4.—The mud from the Sound of Raasay, off the west coast of Ross-shire, was dredged from 150 fathoms, and consisted of very fine soft grey mud, which on washing left a large residue of coprolitic pellets.

No. 5 is a similar mud from Loch Duich, also in Ross-shire ; it harboured many annelids.

No. 6 is from the station in Loch Fyne, where, for the first time, manganese nodules were obtained in comparatively shallow water. It is a sandy clay with many dead shells.

No. 7 is the red clay from 90 fathoms in the Firth of Clyde, off the north-east part of the Island of Arran, which has already been referred to. It is a very fine red ochreous mud, much resembling the oceanic clays. On washing, it is found to be almost completely moulded into coprolitic pellets, and supports an abundant ground fauna. Like oceanic clays, on careful washing, grains of peroxide of manganese can be isolated, and it contains over 1 per cent. of phosphoric acid.

No. 8 is red clay from lat. 18° 56′ N., long. 59° 35′ W., depth 2975 fathoms, in the western basin of the North Atlantic.

No. 9 is a coating of peroxide of manganese from an oceanic concretion, but the locality has been omitted to be noted.

No. 10 is mud from 115 fathoms in the channel between the Island of Searba and the Garvelloch Islands, about twenty miles S.W. of Oban. Peroxide of manganese is very abundant here as a coating on dead shells.

No. 11 is from the upper basin of Loch Fyne, in 60 fathoms. The mud here contains a remarkably large amount of sulphur. The upper basin of a sea loch is, as regards many of its conditions, and notably as regards the nature of the mud at its bottom, in a state intermediate between that of the open sea and that of a fresh-water lake. The mineral constituents are usually in a lower state of oxidation than outside; and this is accompanied by, and partly due to, the relatively large amount of vegetable débris from the land. All these circumstances may retard the disappearance of the sulphur.

Nos. 12 and 13 are globigerina oozes from the Pacific and the Atlantic respectively, their particular locality not noted.

No. 14 is from the same locality as No. 10.

No. 15 is from a position north-east of the Island of Rum, in 147 fathoms, soft grey mud.

No. 16 is a blue mud, from 2050 fathoms in the Celebes Sea.

No. 17 is a glauconitic mud from the east coast of Australia, in 410 fathoms, lat. 34° 13′ S., long. 151° 38′ E.

No. 18 is a diatomaceous mud from the Antarctic Ocean, in 1950 fathoms, lat. 53° 55′ S., long. 148° 35′ E.

No. 19 is a red clay dredged on the 13th March 1874, in 2600 fathoms, lat. 42° 42′ S., long. 134° 10′ E. Along with the mud a large quantity of manganese nodules was brought up.

No. 20 is a radiolarian ooze from the North Pacific, lat. 12° 40′ N., long. 152° 1′ W., depth 2900 fathoms.

Nos. 21 and 22 are again samples of globigerina ooze from the Atlantic and the Pacific respectively. These samples differ from Nos. 12 and 13 inasmuch as the Pacific sample now contains more sulphur than the Atlantic one.

No. 23 is the insoluble residue left after treating a nodule from the same locality as No. 2 with hydrochloric acid and ferrous chloride. The difference is very remarkable. In No. 2 the sulphur was not determined—that is, the barium sulphate produced by its oxidation was not weighed; but it was one of these samples which showed that the amount present was so appreciable that it was worth while determining it as accurately as possible, so that it is certain that it must have contained at least an average amount. In the case of the natural nodule (No. 2) the weight of chloroform residue per 100 grammes substance was 29 milligrammes; in the case of the extracted nodule No. 23 it is 2 milligrammes, and the weight of sulphate of barium is put down as 1 decimilligramme. In fact, the sulphur in the nodule had disappeared under the treatment.

No. 24 is from Loch Fyne, in 87 fathoms, opposite Otter House, and a little further up the loch than the station No. 6, but both of them in the outer loch, as opposed to No. 11, which is in the upper and semi-enclosed basin. The contrast between No. 24 and No. 11 is remarkable. In the upper basin the amount of the chloroform residue per 100 grms. substance was 74 milligrms., and 10 milligrms. of it was sulphur. In the outer loch there were only 17 milligrms. of residue and 1 milligrm. sulphur.

No. 25 is a very remarkable white clay from the bottom of Loch Ness, and therefore a fresh-water formation. It occurs in a small area opposite Urquhart Castle, and in various depths, often covered by a thin layer of peaty substance; but in some places, in depths of about 30 fathoms, the sounding-tube brings up the white clay alone. It was observed also in Loch Oich. It is chemically quite distinct from the marine clays, being much more acid. The amount of matter extracted by chloroform is enormous, being 374 milligrms. per 100 grms., most of which is oil or wax, but containing 4 milligrms. of oxidisable sulphur. It is not impossible that in this case the sulphur may exist as an organic compound; and the amount of oily matter in the clay is interesting in the indication which it gives of the possible mode of formation of our oil-bearing shales.

No. 26 is from the anchorage of Isle Oronsay in the Sound of Sleat.

No. 27 is from a depth of 87 fathoms off Garroch Head, in the Firth of Clyde. Both in this case and in that of No. 26 the amounts of residue and of sulphur are insignificant.

Sulphur was thus detected in all these samples and determined in the greater number of them. Putting aside shallow water coast muds, the largest amounts of sulphur are found in the Celebes Sea (No. 16), in the Diatomaceous ooze of the Antarctic (No. 18), and in the Radiolarian ooze of the Pacific (No. 20). So far, therefore, as it goes, we have the evidence of the sulphur in favour of former organic agency. It is worthy of remark that the property of giving off alkaline water on heating has in the course of years disappeared, and in its place the nodules on being heated give off acid vapours, which, it is true, contain some ammonia, but along with an excess of nitric acid, which is without doubt due to the gradual oxidation of the nitrogenous matter. It is possible that the finely divided sulphur may diminish and finally disappear in the same way. But in 1881, there was still enough to be easily determined. Let us consider the chemical reactions more closely.

When a mud containing ferrous sulphide is treated with dilute hydrochloric acid, the sulphide dissolves with evolution of sulphuretted hydrogen, so long as there is no substance present which has a decomposing action on the sulphuretted hydrogen. If there be

ferric salt either mixed with the mud or in the solution, then it is reduced to ferrous salt, with the destruction of the equivalent amount of H_2S and separation of sulphur. If the ferric salt be in excess, no sulphuretted hydrogen makes its appearance at all. The reaction is very simple—

$$FeS + 2HCl = FeCl_2 + H_2S$$

and $$H_2S + Fe_2Cl_6 = 2FeCl_2 + 2HCl + S$$

$\therefore$ by addition $$FeS + Fe_2Cl_6 = 3FeCl_2 + S$$

because the 2HCl appears on both sides of the equation, and is in fact unnecessary. A *trace* of free acid is no doubt necessary, and it is turned over and over again in the reaction of indefinite quantities of FeS on Fe_2Cl_6, after the manner of a catalytic action.

The same reaction takes place if we use ferric sulphate in place of ferric chloride.

It is evident, therefore, that if we have a sample of mud containing sulphide, and we mix it thoroughly with a solution of Fe_2Cl_6 or $Fe_2(SO_4)_3$, we shall have in the ferric salt reduced a measure of the decomposable sulphide present. The ferrous salt can be readily determined by permanganate of potash or otherwise. It will be seen from the above equation that one molecule FeS decomposes one molecule Fe_2Cl_6 with the formation of three molecules $FeCl_2$, so that the FeS in the mud is one-third of the ferrous salt found.

In order to make some preliminary experiments, a mixture of 100 grms. alum and 30 grms. ferrous sulphate were dissolved in about $\frac{3}{4}$ litre of water and precipitated with ammonia and sulphide of ammonium. The precipitate was thoroughly washed by repeated decantations, the flask being always filled up to the neck, and corked and allowed to settle. When it was completely washed the surplus water was poured off, and the precipitate, suspended in about $\frac{1}{2}$ litre of water, was preserved in a well-stoppered reagent bottle. The precipitate consists of alumina and sulphide of iron, and may therefore be taken as an imitation of a simple form of mud. I made some experiments to see with what amount of agreement in the results one could titrate a number of different samples of the same mud.

Three flasks were placed side by side, and into each 50 c.c. suspended FeS mud were measured. The mixture of $FeS + Al_2O_3$ was

thoroughly shaken up, then run into a narrow graduated cylinder, holding 50 c.c., which was emptied into the flask and then washed once into it with distilled water. To each of the flasks was then added 10 c.c. of the reddish-brown but still acid, ferric sulphate solution, and the contents shaken. In a few seconds the black colour of the sediment had disappeared entirely, being replaced by a yellowish-red precipitate, which disappeared for the most part on the addition of dilute sulphuric acid. Water was then added to bring up the volume to 250 c.c., and the titration was effected with permanganate of potash solution $\left(1 \text{ litre containing } \frac{KMnO_4}{50} \text{ grms.}\right)$. The three portions of 50 c.c. required each 11·6, 11·6, and 11·7 c.c. permanganate respectively. We see then that a suspended precipitate can be measured off about as accurately as a dissolved salt.

It is evident, then, that if we have a mud containing FeS and other ferrous compounds decomposable by HCl, we can determine first the FeS by adding Fe_2Cl_6 and titrating a portion with permanganate; then the other ferrous compounds, by adding HCl and titrating another portion with permanganate, due account being kept of the weights and volumes used. In order to try the method in practice, three soundings were made;—on 30th September 1881 in the Sound of Raasay, off Croulin Island, 120 fathoms; and on the 1st October 1881 in Loch Duich, in 49 and 51 fathoms. The first of these represents more or less the conditions in the open sea of coast waters; the last two represent the conditions in a semi-enclosed loch basin. The Sound of Raasay mud was a light grey mud, with no offensive qualities. Both samples from Loch Duich were very foul smelling. All three samples were tightly stoppered up in their wet condition, and examined on 20th and 21st October 1881 in my laboratory in Edinburgh. I unfortunately had no suitable ferric solution afloat with me so as to treat them immediately. In the three weeks that both muds from Loch Duich were kept in bottles, the surface layer got completely oxidised, and on opening the bottles the smell was gone; but, on breaking through the surface layer, the unaltered black mud was exposed with all its original qualities, including its peculiar odour.

The following was the method used in the case of the Loch Duich

mud from 49 fathoms. Two portions of the damp unaltered mud were weighed out; one portion, 6·724 grms., was dried at 100° C., and the other, 7·881 grms., was treated with deep red Fe_2Cl_6 in a 100 c.c. flask, which was then filled up to the mark with water. 50 c.c. of this solution, containing 3·94 grms. damp mud, were acidified with sulphuric acid and titrated with permanganate $\left(\frac{KMnO_4}{50}\text{ grms. per litre}\right)$, using 1·9 c.c. To the remaining 50 c.c. with sediment (the volume of which may here be neglected) were added 4 c.c. of strong hydrochloric acid (12·5 HCl grms. per litre), filled up to the mark, and allowed to settle. 50 c.c. of this solution, containing 1·97 grms. damp mud, were further acidified with sulphuric acid and titrated with the same permanganate, of which 1·7 c.c. were used. A litre of the above permanganate oxidises 5·6 grms. iron from the ferrous to the ferric state. In the first operation, 50 c.c. solution used 1·9 c.c. permanganate, therefore the whole amount of mud, 7·881 grms., when treated with ferric chloride, would require 3·8 c.c. = 0·0213 grm. iron.

After treatment with hydrochloric acid a quantity of solution equivalent to 1·97 grms. wet mud required 1·7 c.c. permanganate, so that 7·881 grms. mud would require 6·8 c.c. when treated with both HCl and Fe_2Cl_6, which represents 0·0381 grm. iron. Therefore, total iron found by

Permanganate in HCl + Fe_2Cl_6 solution, . .	0·0381 grm.
Deduct Iron found in Fe_2Cl_6 solution, . .	0·0213 ,,
Leaves Iron present as Ferrous Salt extracted by Hydrochloric Acid, ...	0·0168 ,,

Of the 0·213 grm. iron found in the first solution we have seen that only one-third is to be reckoned as belonging to the mud, and to be taken as forming FeS, so that in 7·881 grms. wet mud we have 0·0071 grm. iron present as sulphide, equal to 0·0112 grm. FeS, and 0·0168 grm. iron present as ferrous oxide extracted by hydrochloric acid, equal to 0·0216 grm. FeO.

The 6·724 grms. wet mud weighed when dried at 100° C., during which it was oxidised as well as dried, 2·011 grms., equal to a loss of 70·1 per cent. Therefore the dry mud is 29·9 per cent. of the damp mud taken. The 7·881 grms. damp mud therefore represent

2·3564 grms. dry mud, and therefore we find that the mud taken as dry contains 0·47 per cent. FeS and 0·92 per cent. FeO in some other easily decomposable combination.

The other samples were treated in the same way, and in the Loch Duich mud, from 51 fathoms, 0·94 per cent. FeS + 0·65 per cent. FeO were found. It is remarkable that the amount of F_2S should be so small in such offensive muds.

In the outside mud from 120 fathoms in the Sound of Raasay only 0·05 per cent. FeS and 0·1 per cent. FeO were found.

In connection with this mud, which contained some shell debris, the method was found to be less applicable than to muds free from calcareous matter. The reason is obvious; because, on adding a neutral ferric solution to a mud containing carbonate of lime, precipitation of the ferric oxide by the lime immediately commences. This would not really interfere with the reaction, because the FeS would reduce the precipitated Fe_2O_3 all the same, and the ferrous salt can still be determined by permanganate; but in truly calcareous bottoms this action is troublesome, and the method will require special study in this direction. In the semi-enclosed basins of the sea lochs, which, as has already been observed, form a transition between the open sea and fresh-water lakes, the bottom resembles more nearly that of the fresh-water lakes, in the absence of mollusca, and in the abundance of organic matter of vegetable origin, than that of the open sea with its abundant and varied ground fauna. It differs from those of fresh-water lakes in being bathed by sea-water largely impregnated with sulphates. Consequently it is in the inner basins of sea lochs that the conditions for a constant production of sulphides are present, while the same conditions are hostile to the presence of calcareous organisms. Hence it is in these basins that the greatest quantities of sulphides are found, and it is in their muds that the above method is most applicable.

The sulphuretted muds, however, are so alterable by atmospheric influences that it is essential that they should be treated immediately on collection. For this purpose weighed wide-mouthed bottles with good stoppers should be provided. When a specimen of mud is brought up from the bottom, a sample of it is immediately taken with a spatula and put into one

of these bottles containing a known quantity of ferric chloride solution, at least sufficient to completely cover the sample of mud. Another sample, as nearly similar to the first as possible, is taken and stoppered in another bottle for drying. In this way a large amount of valuable information might be gained; but it will be evident from the nature of the case that the actual figures obtained in any one particular case are affected by a considerable possible error.

In the month of June 1881 I carried out a number of laboratory experiments bearing on this subject, using the sulphides of different metals of the iron group. These bodies were all prepared in the same way, namely, by precipitating the sulphates with sulphide of ammonium, and washing by decantation in stoppered bottles, always filled up quite full. A quantity of hydrated ferric oxide was also prepared by precipitating ferric chloride with ammonia and washing. All of these precipitates, when thoroughly washed, were preserved suspended in distilled water in well-stoppered reagent bottles.

Ferrous Sulphide and Ferric Oxide.—When quite neutral these substances do not react on one another, at least at once. But if the water has the slightest acid reaction reduction of the sesquioxide and production of sulphur take place rapidly. A mixture of Fe_2O_3 and FeS in water and quite neutral was corked up and allowed to stand for five days, when the sediment was found to be separated into two sharply-defined layers—the upper red, consisting of the oxide, and the lower black, of the sulphide. When brought together, therefore, in presence of nothing but distilled water, there is no appreciable resultant action.

Manganous Sulphide can be preserved perfectly under distilled water in well-stoppered bottles filled to the neck. A considerable quantity was prepared in the summer of 1881, and, when thoroughly washed, it was put away in three separate bottles. The contents of only one bottle were used for experimental purposes, and the upper part of it got coloured immediately black with oxide of manganese, from the oxidation of the flakes of sulphide which adhered to the surface of the upper part of the bottle, left dry when some of the water and precipitate had been poured out. This took place at the time, and was to be expected. The two other bottles, which were

filled up with the manganous sulphide at the time of preparation, have never been opened since, though they have all the time been exposed to the light, and are exactly in the condition in which they were when bottled nine and a half years ago. There is no trace of oxidation.

Manganous Sulphide and Hydrous Ferric Oxide.—Both substances are used, suspended in distilled water. If the ferric oxide be cautiously added to the sulphide of manganese, and both suspended in water, the red patches are seen to disappear, and the general colour of the suspended matter becomes rather lighter in colour than the MnS, and there is no formation of FeS. If further additions of Fe_2O_3 be made, red flakes deposit themselves. They do not appear to be unaltered Fe_2O_3, but are exactly like the "red cherty particles" of manganese bottoms. On still further additions of Fe_2O_3, the colour changes quickly, though not instantaneously, to black, with, however, a large admixture of white particles, the two being easily seen to be perfectly distinct. There is also a quantity of precipitated sulphur which remains floating in the liquid long after the heavy matter has subsided.

Prosecuting this line of experiment, I made three mixtures in suitable flasks.

No. 1 contained MnS and Fe_2O_3, the MnS being in excess. There was formation of red cherty particles, but nothing black.

No. 2. The same substances, but containing the Fe_2O_3 in excess; the mixture quickly turned black.

No. 3. The same as No. 2, only it was made up with warm water, and it turned black almost at once.

These experiments were repeated, and with the same results. The above flasks, Nos. 1, 2, and 3, were corked up and allowed to stand over night. No. 1 contained numerous black particles, as well as red cherty ones, and an excess of MnS as well as sulphur. Nos. 2 and 3 were much as they had been the night before, except that the white particles had almost entirely disappeared, as also all red particles. The reactions are considerably accelerated by heat.

On examining the contents of each of these flasks, no peroxide of manganese was found, but large quantities of sulphide of iron. The likeness in the red flakes to the cherty particles of the bottom muds in the manganese districts of the South Pacific. and of the

kernels of some manganese nodules was very striking. It is not improbable that the first action of the MnS on the Fe_2O_3 may be accompanied by the formation of mixed oxides of iron and manganese; but there is much to be done in this direction in the strictly quantitative investigation of the interaction of the insoluble, but not inert, compounds of this as well as of other groups of metals.

Ferric Sulphate and Manganous Sulphide.—Experiments were now made, using the iron as a ferric salt in solution, and for this purpose ferric sulphate was used. It was made as nearly neutral as possible by addition of ammonia. The MnS was, as before, suspended in distilled water.

On adding ferric sulphate to excess of MnS, the formation of FeS is immediate.

On adding a large excess of $Fe_2(SO_4)_3$ the FeS is decomposed, there is formation of basic salt, and on dissolving it with H_2SO_4 the solution contains large quantities of ferrous sulphate.

On experimenting with solution of ferrous sulphate it was found that excess of MnS precipitates the iron completely as FeS, acting exactly like an alkaline sulphide.

The rationale, therefore, of the above reaction is very simple. Thus

$$Fe_2(SO_4)_3 + MnS = 2FeSO_4 + MnSO_4 + S \quad . \quad (1)$$

and

$$2FeSO_4 + 2MnS = 2FeS + 2MnSO_4 \quad . \quad . \quad (2)$$

$\therefore$ adding (1) and (2) we have

$$Fe_2(SO_4)_3 + 3MnS = 2FeS + 3MnSO_4 + S \quad . \quad (3)$$

and

$$2Fe_2(SO_4)_3 + 2FeS = 6FeSO_4 + 2S \quad . \quad . \quad . \quad . \quad (4)$$

and $(3)+(4) = 3Fe_2(SO_4)_3 + 3MnS = 6FeSO_4 + 3MnSO_4 + 3S \quad . \quad (5)$

$$\text{or } \frac{(5)}{(3)} = Fe_2(SO_4)_3 + MnS = 2FeSO_4 + MnSO_4 + S \quad . \quad (6)$$

which is identical with (1), and by adding more MnS we get the conditions of equation (2), and so on, repeating the cycle.

Hence, if we add MnS to excess of $Fe_2(SO_4)_3$, we should get reduction of the ferric salt without formation of FeS. On adding excess of MnS, we get formation of FeS, and then on adding excess of $Fe_2(SO)_4$ we get back to the same state of things as at first.

The reaction of equation (1) can be obtained by very cautiously adding small quantities of suspended MnS to a very large excess of

$Fe_2(SO_4)_3$. Still there is always local formation of FeS which disappears on mixing, so that the reaction is really that of the whole cycle. The action, therefore, of MnS on soluble iron salts is in the first instance to reduce whatever is in the ferric state to the ferrous, and then at once to precipitate the ferrous salt as sulphide, a manganous salt taking the place of the ferrous salt in the solution.

When added in great excess to solutions of nickel sulphate, manganous sulphide precipitates it as NiS. When added to solution of sulphate of zinc, it either does not precipitate it at all or only very slightly at ordinary temperatures. Sulphide of zinc was not found to precipitate manganese sulphate solution.

As the result, then, of the observations and experiments which have been recited I was led to believe that the principal agent in the comminution of the mineral matter found at the bottom of both deep and shallow seas and oceans is the ground fauna of the sea, which depends for its subsistence on the organic matter which it can extract from the mud.

In order to fit them for collecting their nutriment in this way the animals have been fitted with different forms of masticating or milling apparatus, so as to thoroughly deal with the matter which they pass through their bodies. It has been shown that most silicates are decomposed to a certain extent when ground or pulverised under water; so that the mere mastication of the sand or mud in presence of pure water would have a decomposing action on the silicates which it contains. This action is much assisted, in the case of marine animals, by the fact that the water which they pass through their bodies along with the sand is charged with sulphates. These are easily reduced to sulphides by the action of the organic matter of the secretions of the animals. The resulting sulphide at once suffers double decomposition with any oxide of iron or manganese which is present as such in the mud, or may be being set at liberty from silicates under the decomposing influence of trituration under water. The sulphides of manganese and iron so formed are in course of nature extruded by the animals, and if exposed to the sea water on the surface of the mud are quickly oxidised, the manganese taking priority. The mud below the surface layer, in localities where ground life is abundant, remains blue, being protected by the oxidation of what is above it.

At the bottom of the ocean the mineral matter is thus exposed to a reducing process due to the life of the animals which inhabit it, and to an oxidising process due to the oxygen dissolved in the water. Other things being equal, the redness or blueness of a mud or clay depends on the relative activity of these processes. They also exercise a controlling or modifying influence on one another. For, although marine animals are much less sensitive to variation in the amount of oxygen in their atmosphere than terrestrial animals, it is certain that there must be a limit to the deficiency of oxygen which each animal can support; and when this limit is approached, its reducing activity is diminished, or, it may be, extinguished. The water in the course of circulation is being continually renewed, and, meeting with a diminished amount of freshly reduced matter, it is able to push the oxidation of the mud to a greater depth. It is easily conceivable that in many of the deep parts of the ocean the amount of ground life may be so limited that the water has no difficulty in oxidising at once its ejecta; and these conditions would be favourable to the formation of a red clay or chocolate mud according to the preponderance of iron or manganese.

While dealing with this subject it is proper to refer to Darwin's book on *Vegetable Mould and Earthworms*, which was published in 1881. His masterly investigations in the kindred department of the part played by earthworms in the formation of the terrestrial soil strengthened me much in my belief in the soundness of the views above developed as to the formation of marine muds. Indeed, to a certain extent he extends his views himself to the case of marine muds. At page 256, after noticing that it is due to the milling action of the gizzards of worms that the supply of exceedingly finely divided mineral matter, which is removed from the surfaces of every field by every shower of rain, is constantly renewed, he adds in a note: "This conclusion reminds me of the vast amount of extremely fine chalky mud which is formed within the lagoons of many atolls, where the sea is tranquil and waves cannot triturate the blocks of coral. The mud must, so I believe, be attributed to the innumerable annelids and others animals which burrow into the dead coral, and to the fishes, Holothurians, &c., which browse on the living corals." Darwin further gives an

approximate numerical result or estimate of the work of earthworms which is interesting. At page 258 he says: "Nor should we forget, in considering the power which worms exert in triturating particles of rock, that there is good evidence that on each acre of land which is sufficiently damp and not too sandy, gravelly, or rocky for worms to inhabit, a weight of more than 10 tons of earth annually passes through their bodies and is brought to the surface."

On a Simple Pocket Dust-Counter.

By **John Aitken**, Esq.

(With a Plate.)

(Read December 1, 1890.)

It is now a year and a half since I communicated to this Society a description of a portable form of apparatus for enabling us to count the number of particles of dust in the atmosphere. The working of that instrument in my hands has been most satisfactory, and though it has occasionally given trouble, yet it has not given more than might have been expected. Though that apparatus has worked quite pleasantly with me, and enabled a beginning to be made of an investigation into the amount, and the effects, of dust in our atmosphere, yet very few have as yet followed up this line of inquiry. This has probably been owing to there being something in the complicated nature of the apparatus which has deterred others from joining in the work. I therefore determined to see if a simpler, and at the same time a reliable, form of the apparatus could not be devised.

After the experience gained in making thousands of observations with the portable apparatus, I have acquired an acquaintance with its weak points, and a knowledge of what it would be necessary for an instrument of this kind to do under the different conditions in which it would be required to work, and I may now sum up the indictment against the portable apparatus under the following heads:—It is too complicated; it has too many weak points; it is too heavy; it has an unnecessarily wide range for meteorological work; and it is too expensive. If an instrument could be con-

structed free from the first four charges, it is probable the fifth would vanish.

First, as regards weight, the experience gained with the portable apparatus has shown that the size may be very much reduced if the instrument is to be used only for testing air of country districts—*i.e.*, air free from immediate local pollution. Experience has shown that in country air the number of particles is rarely over a few thousands per cubic centimetre. It is therefore not necessary to use the small measures of the portable apparatus under these conditions, as we can with the air-pump alone test air up to an impurity of 25,000 per cubic centimetre. It is only for air of greater impurity than this that the stopcock measures are required. These small measures may therefore be omitted. Again, when testing country air, the proportion of pure air to impure air required to make a test does not vary greatly—from 4 to 1 to 19 to 1. The receiver of the instrument does not therefore require to be so large as when the air to be tested requires to be mixed with some hundred times its volume of pure air. This admits of the receiver, and therefore of the whole apparatus, being greatly reduced in size. The capacity of the receiver in the pocket instrument has therefore been reduced to one-fifth of that of the portable apparatus. This at once effects a great reduction in the weight, and the stopcock measures not being required reduces the expense as well as the weight.

Turning now to the weak and troublesome parts, these are principally :—(1) The air-pump valves are liable to get out of order, and occasionally give rise to trouble. (2) The india-rubber tube for closing the opening through which the stirrer-rod passes occasionally fails, and gives trouble by leaking. Further, these india-rubber tubes with closed ends require to be specially prepared for the instrument, and it is difficult to get suitable tube for the purpose. And (3) the silver counting stages are delicate and troublesome to keep. So far as my experience goes this is not the case, as after a little practice no trouble has been experienced, and the first silver stage put into my instrument is still in use and in good condition. My experience, however, is not that of others, and it seemed in the highest degree desirable that some improvement be made in this direction by the introduction of a counting stage that could be more easily kept in working order.

Returning now to the first weak point, viz., the air-pump valves, reference to the Plate given with this paper will show how this difficulty has been overcome. The figures on the plate show the new pocket instrument drawn full size. In the figures, R is the receiver, and P the pump. It will be observed that the receiver R communicates with the pump P by means of the stopcock K, and it will be noticed that all difficulty with the valves is got over by simply removing them altogether, and making the stopcock K act the double part of air-pump valves, and valve for admitting the air to be tested. The passage through the plug of the stopcock K is not straight, but is bored at right angles as shown. It will also be noticed that there are three ports in the body of the stopcock—one communicating with the pump P, one with the receiver R, and one with the outer air.

It will be observed that the lower part of the air-pump is similar in design to that of the portable apparatus. The continuation of the pump-barrel G forms a guide for the piston-rod of the pump, and has a scale graduated on it to enable the observer to introduce into the receiver different proportions of impure air for testing. At fig. 4 is shown a separate drawing of the guide-tube, and on it is shown the scale marked with the figures $\frac{1}{50}$, $\frac{1}{20}$, $\frac{1}{10}$, $\frac{1}{5}$. This scale is so divided that when the guide-collar is drawn down to those respective marks it enables us to introduce into the receiver measured quantities of impure air, such that when mixed with the pure air in the receiver and expanded there will be these proportions of impure air in the receiver. So that on making a test and counting the number of drops per cubic centimetre in the mixed and expanded airs in the receiver, the number so obtained must be multiplied by the proportion of impure air used. Suppose, for instance, that we drew down the pump to the $\frac{1}{20}$ mark on the scale, and on testing the mixture of this amount of air with the pure air in the receiver, and observed, in say, ten tests, an average of two drops per square millimetre, then as there is one centimetre of air above the counting stage, two drops per square millimetre will be 200 per cubic centimetre in the air of the receiver, but this figure must in this case be multiplied by 20 to get the number of particles in the outer air, which in this case would be 4000.

The guide G is fitted to the cylinder cover of the air-pump by

means of a screw to enable it to be taken to pieces for the convenience of packing. The piston of the air-pump is packed with the usual cupped leather. To this I have added a small spring ring, as shown in drawing, at the lower part of the piston. This ring, so far as experience yet goes, has been found to be an advantage, and has kept the piston always tight with varying degrees of dryness of the leather.

The second weak point in the portable apparatus, to which reference has been made, is the india-rubber tube making the air-tight joint between the rod of the stirrer and the receiver. Here, again, as will be seen from the drawing of the pocket instrument, the difficulty has been got over by simply removing it, and closing the end of the tube with a metal cap. This is possible in the pocket instrument, because we can move the stirrer without touching it. It is only necessary to invert the instrument, when the stirrer drops to the other end, and on again bringing the instrument to its original position, the stirrer again drops to the bottom. These movements are made two or three times to make the mixing thorough. Some little attention is necessary in the construction of the stirrer. It will not do to put a diaphragm into the receiver and allow it to fall anyhow. The effect of that would be to manufacture a great quantity of nuclei, and copious showers would invariably follow its use. These showers are caused by nuclei formed by the wet surface of the stirrer splashing on the wet surface of the receiver. It will be seen from the drawing that the stirrer is caused to move truly by means of a small rod fixed in it, and projecting downwards. The lower end of this rod enters a tube which projects through the bottom of the receiver, the lower end of this tube being closed. Both ends of the guide-rod are pointed to reduce this splashing surface to a minimum. When the instrument is inverted, the falling stirrer keeps parallel to the top and bottom of the receiver, but touches neither, save at the points, and nuclei are rarely formed. As in the other instruments, both sides of the stirrer and the bottom of the instrument are covered with blotting-paper, cemented on with india-rubber solution. The blotting-paper is kept moist to saturate the air, and supply water for the rain drops, when the entering air is dry.

On referring to the drawing it will be seen that there is no

filtering apparatus attached to the pocket instrument. With the removal of the air-pump valves its use would be inconvenient, and it is not a necessary part of the apparatus. For viewing the counting stage the magnifying lens M is used. A common single lens of about two-centimetre focus does very well for the purpose. It is lighter and less expensive than a compound one. The lens is mounted in a tube which slides into another tube, this larger tube is attached to a disc of brass of the same diameter as the top of the receiver. This disc has a flange all round it of such a size that, when cut so as to give it a spring, it grasps the top of the receiver firmly, but in such a way that it can be easily lifted off. This is necessary, as the inside of the glass cover of the receiver often gets dewed, and the easiest way of removing the condensed moisture is to lift off the cover carrying the lens, and hold the finger on the glass to heat and evaporate the moisture from the inside surface.

Before proceeding to describe the improvements in the counting stage, it will be as well to describe the manner of using the new instrument. The first thing to be done is to see that the inside of the receiver is wet. If it is, then examine the inside surface of the glass cover of the receiver, and see if it is free from condensed moisture, which would interfere with a clear view of the stage. If it is not clear, take off the metal cover and hold a finger on the centre of the glass plate till it begins to clear, and then replace the cover. Too much heating should be avoided, as it gives rise to trouble with the counting stage. Now examine the surface of the counting stage, and see if it is free from specks. If it is not satisfactory, take it out and clean it with a piece of clean cloth. Care is advisable in doing this to see that the cloth is perfectly clean, as otherwise the stage will look dirty and streaky in the humid atmosphere in the receiver. If the stage is simply dewed, then touch the underside of it with a finger to heat it slightly. If the finger is not quite clean, put a thickness of cloth or other protection over it. If these two glass surfaces are in good order, the instrument is ready for making a test.

If it has been necessary to take the counting stage out of the receiver to clean it, then this will have admitted much impure air, and as there is no filter to enable us to fill the receiver with pure

air, we must now purify it in another way. To do this the stopcock A is closed, and the stopcock K is turned so as to put the pump into communication with the receiver, that is, in the position shown in fig. 1. A stroke of the pump is now made. This causes condensation to take place on the dust particles when some of them drop out of the air. The piston is again put to its top position, and another stroke made, when more particles settle, or are deposited on the sides by the rush of air. After this expanding and condensing process has been done a few times all the particles of dust will have become nuclei, and be deposited on the bottom of the receiver. The air will now be pure, no drops falling when expansion is made. This process of purifying the air in the receiver is quite as quick as the filtering one. Indeed, when the filtering process is used, it is always quicker to end by showers of the last particles.

The air in the receiver being now purified so that no drops are seen falling when expansion is made, the next thing to be done is to introduce into the receiver the necessary quantity of the air to be tested. However, before doing this, it is advisable to turn the stopcock K a quarter turn to the left, so as to bring the receiver into communication with the outer air. The object of doing this is to bring the pressure inside the receiver to that of the open air. When making the repeated expansions to purify the air in the receiver, some air may have leaked in past the piston, and it is to get rid of this air that the stopcock is opened and the receiver put into communication with the outer air before taking in the measured quantity. If this was not done the amount measured in would be too small by the amount of the leakage. There will be no leakage if everything is in good working order; still it is a good precaution always before taking in the air to be tested to turn the stopcock and allow any plus pressure to escape.

The air in the receiver being at the same pressure as the outer air, the measured quantity of the air to be tested is then taken into the receiver in the following manner:—The piston being at the top of its stroke, where it ought always to be at the end and beginning of every test, and the stopcock in the position shown in the drawing, the piston is then drawn down the amount that is thought will be suitable under the conditions. Say it is drawn down to the $\frac{1}{10}$ mark on the scale, by this movement there is taken out of

the receiver a measured quantity of air. The stopcock K is now turned one quarter turn to the left, so as to bring the inside of the receiver into communication with the outer air. When this is done the measured quantity of air rushes into the receiver. The quantity of air we have taken out of the receiver to make room for the air to be tested is, however, still in the pump, and must now be got quit of. To do this it is only necessary to return the piston to the top of its stroke before turning the stopcock back again to bring the receiver into connection with the pump. When the stopcock K is turned to the position to admit the outer air to the receiver, it will be seen from the drawing that the pump is then also in communication with the outer air by means of a small passage drilled longitudinally through the plug of the stopcock. By this arrangement only one movement of the stopcock is necessary for admitting the air to the receiver, and opening the discharge valve of the pump, and when the stopcock is again turned to bring the receiver into connection with the pump, the discharge valve is closed. From this it will be seen, that though we have dispensed with the air-pump valves in this new arrangement, we have not increased the number of stopcocks required, nor the number of movements necessary for making a test.

The necessary quantity of air being admitted to the receiver, and the pump emptied, and the stopcock turned to its original position, so that the receiver is in communication with the pump, the instrument is then inverted so as to cause the stirrer to drop inside the receiver, and again brought to its vertical position when the stirrer again drops. This is done two or three times to mix the impure air with the pure air in the receiver. When this is done, the instrument is held, with the top of the receiver horizontal, and in a convenient position for the observer viewing the counting stage through the magnifying glass. Expansion is then made, and the number of rain drops counted in the usual way. If in this trial more than five drops fall per square millimetre, then too much impure air has been taken in, and a smaller proportion of impure air must be used to get a correct test. From the number of drops observed it is easy to determine whether $\frac{1}{20}$ or $\frac{1}{50}$ will be the best proportion to use for testing under the existing conditions. On the other hand, if, in this preliminary

trial, less than one drop per square millimetre fell, then the quantity of impure air ought to be increased to, say, $\frac{1}{5}$ impure air. Sometimes, however, the air is so pure that $\frac{1}{5}$ is too little, and it is desirable to have no pure air in the receiver, and to fill it entirely with the air to be tested. When this is the case, the stopcock K is turned so as to put the receiver into communication with the outer air, and the air is drawn out of the receiver through the stopcock A. This may be done either by means of the mouth, or by any simple piece of apparatus. The current must be kept flowing through the receiver till all the pure air has been drawn out. After this the stopcock A is closed, the receiver put into communication with the pump, the stirrer worked, expansion made, and the drops counted in the usual way. When working in this way the number obtained per cubic centimetre in the air of the receiver has to be multiplied by 1·4 to allow for the reduction in number produced by the expansion. When working in pure air it is often necessary, instead of confining the attention to one square millimetre, to observe the number of drops that fall on a square of four squares, or on a square of nine squares, that is, of nine square millimetres.

Having described the manner of working the new apparatus, we shall now proceed to describe what has been done to improve the counting stage, and make it more simple and easily kept in working order. Naturally glass seemed the most suitable substance for making those stages on account of the perfection of its surface, as well as for the ease with which it can be kept clean. I had previously tried glass, but with no good results; but though I had hitherto failed, the many advantages to be derived from the use of glass induced me to make a fresh attempt. The difficulty with glass is that the drops when they fall on it are nearly invisible. It does not matter whether we use glass mirrors or blackened glass—in all cases it is difficult to see the drops. On examining into the cause of this difference between glass and silver surfaces, water spray was allowed to fall on these surfaces, and the drops were then examined by means of a magnifying lens as they rested on the different surfaces. It was seen that on the silver, the drops scarcely touched the surface, but formed little flattened balls, and their brilliancy is due to the light reflected from the internal concave surface furthest from the light; whereas the drops on glass adhere

to and spread themselves over it, more or less, but there is no internal reflection, and only a slight external one on the convex side next the light.

The problem then came to be—Could it not be possible to prevent the drops adhering to and spreading themselves on the glass? In some trials I got encouragement to suppose this might be possible by coating the surface of the glass with some substance that would repel the water. The manner of testing this was to coat a clean plate of glass with the substance under trial, allow a shower of spray to fall on it, and examine the drops with a lens. In this manner many substances were tried, but the best results were got with paraffin-wax and refined beeswax. These substances were put on the glass, and then rubbed off till their presence could scarcely be detected. Glass so treated was found to act exactly like silver; the spray rested on the surface in little round balls, and showed the internal reflection well.

These substances were then tried in the dust-counter, on small silvered glass counting stages, and it was found that they did perfectly under certain conditions, but it was difficult always to secure these conditions with the very small pieces of glass. The treatment was tried in practice for a time, but it was found to be troublesome, as it did not always produce the desired result. The plan was therefore abandoned as it was not thought good enough, nor sufficiently simple, and certain in its action, to be put into the hands of most observers.

Experiments were therefore begun in another direction, and trials made of the effect of illuminating the stage from beneath. If we place a mirror underneath the glass stage so as to reflect the light of the sky through the stage, no satisfactory result is obtained owing to the general glare of light. However, I have fortunately succeeded in lighting the stage from beneath in such a way that not only are the drops visible, but they are seen with a distinctness far superior to anything yet obtained, even with silver in its best condition and best lighting. Not only so, but a very low degree of illumination is sufficient to show the drops clearly. One great advantage of this is, that observations can be made in early morning and late evening, when the light is far too feeble for working with silver.

This method of illumination is shown in the drawing of the instrument (see figs. 1 and 3). The counting stage is made of glass, and is illuminated from beneath, the light being reflected upwards by what we might call a spot-mirror, which is simply an ordinary mirror with a black circular space in the centre. This enables the drops to be illuminated by means of a slightly oblique light, while an image of the black spot covers the field of the lens. The result is the drops are seen shining brilliantly on a nearly black field, and are counted with great ease.

After satisfying myself of the value of this method of working, a difficulty presented itself. I had an ordinary micrometer made of a size suitable for the counting stage. This micrometer was made by a professional maker of these instruments; but on fitting it into the dust-counter, the method of illumination was found to be so powerful and trying, that it brought out all manner of imperfections and blemishes on the micrometer which were not seen with a magnifying glass and ordinary illumination. The cross lines on the micrometer looked rough, with a crystalline glistening appearance, and there were so many specks on its surface that working with it was very difficult, as few squares were free from spots, which were apt to be counted as drops. The makers of the micrometer were therefore written to about these imperfections; their reply was that "they had done their best, carefully selecting the glass, &c., and that they thought it would be difficult to get a better instrument." If better could not be got, I felt that the value of the new arrangement would be greatly decreased. I therefore determined to attempt the manufacture of micrometers myself, to see what could be done. A piece of patent plate-glass was procured, this was cut into suitable sizes and very carefully examined with a strong lens, while it was illuminated by means of a spot-mirror. After finding a fairly good piece in the glass, any specks which were on its surface were tested with a pointed piece of soft wood, and if they were not found to be removable, the part was rejected and the search continued. In this way a few pieces were obtained large enough for the purpose, and perfectly free from specks. These perfect pieces were marked off on the glass, cut out, and fine cross lines at one millimetre apart were engraved on their surfaces; after which they were turned into little circular discs of the required diameter.

Two methods of engraving these lines have been tried, and both of them give much better lines for the purpose than is obtained by the usual method of engraving micrometers. One method is to cover the glass with beeswax, and draw the lines with a fine needle point, and then etch with hydrofluoric acid. The lines obtained by the use of ordinary hydrofluoric acid are not very suitable, as they require to be of some breadth before they are visible with the spot-mirror illumination, and they then show as bright glistening lines. The mixture known as "white acid," however, gives a fine line with just that degree of white visibility which makes them appear clear without glancing and distracting the attention. In this manner the micrometer which is at present in use was prepared, and it has been found in every way satisfactory. The vapour of hydrofluoric acid also gives good results. In etching these lines, trial must be made with the acid and a piece of the same glass to find the correct time the micrometer requires to be kept in the acid to etch to the required depth, the trial pieces being tested under the spot-mirror illumination. The difficulty of drawing these lines with a diamond is, that when they are made strong enough to be easily seen, they have always bright spots on them.

It will be observed from the drawing that these micrometers or counting stages are made of thick glass. The object of this is to prevent any speck, or anything adhering to the under side of the glass, interfering with the clearness of the field. The thickness of the glass puts them so much out of focus that they do little harm. There is then, therefore, no real barrier to the use of these micrometers, only the glass must be selected when under the illumination of a spot-mirror. It may be remarked here that the spot-mirror may be found useful for other purposes. It gives us a powerful means of detecting flaws in lenses, &c. The surface of a new lens when examined by means of it looks so full of imperfections that it seems scarcely possible it can give a perfect image, while the imperfections must give rise to the dispersion of a good deal of light.

The other method of engraving the lines on the glass, which has been tried and found to give good results, is to cover the glass with very fine emery powder, wetted with turpentine, and scratch the lines with a needle point; or better, to tip the needle with a little diamond bort. The fineness of these lines can be made

all that is desired, and there is little trouble from the needle blunting under the operation. In ruling these lines, it is, of course, necessary to keep the pressure on the needle constant, and to make the same number of strokes across the glass for each line, in order that the lines may be equally thick.

The pocket instrument has been occasionally in use during the whole of this summer, first with a silver stage and then with a glass one, and has been working quite satisfactorily, and giving results agreeing with those of the larger instrument. The instrument appears to be now so simple, it can be easily worked by any one. So far as can be seen at present, the weakest point in the instrument now, and the only one likely to cause trouble, is the piston packing. If the piston is not tight, correct work cannot be done. Fortunately, the conditions of testing make it impossible, with ordinary care, to make a test with a badly-fitting piston; because it would be impossible with it to thoroughly purify the air in the receiver. When air leaks in past the piston, nuclei are admitted, and these prevent the showers in the receiver ceasing completely. If the piston leaks a little, at each stroke of the pump, though no air has been admitted by the stopcock, a few drops will be seen falling, and call the attention of the observer to the imperfection.

To reduce the trouble from this cause as much as possible, I have introduced the spring ring already referred to, under the leather cup packing, and so far this has worked well; the piston has given no trouble since its introduction. One objection to the cup leather packing is, that if it gets out of order the repair of it might not be within the powers of the observer. To obviate this objection, the arrangement shown in fig. 5 has been designed, tried, and found satisfactory. It consists simply of the substitution of a plunger-pump for a piston one. The advantage of the plunger is, that any one can easily pack the stuffing-box, and some kind of material for doing it can always be obtained. In appearance, the plunger-pump is not so compact as the piston one, on account of the diameter of the stuffing-box requiring the guide-tube to be made of much greater diameter. Yet this is little disadvantage so far as compactness for packing is concerned, as the pump-barrel can be slipped inside the guide-tube, when unscrewed for packing in its case.

It may be asked—Does this simple instrument displace the more complicated earlier forms of the apparatus? Have the earlier forms been unnecessarily complicated? The answer to this is—That the pocket instrument is designed for special work, and only for that work; while the earlier forms are still necessary, and can do work in conditions in which the pocket instrument would be useless. The large instrument fitted up in the Ben Nevis Observatory, with its arrangement of circulating pipes, aspirator, and artificial illumination, is still the best form for a first-class observatory, where observations have to be made in all weathers, and during night as well as day. The Portable instrument is still necessary when we wish to test locally poluted air, such as that near human inhabitations, that is for sanitary work; while the use of the Pocket instrument is confined to meteorological work in the open air, and its advantages are simplicity and lightness.

It may be remarked here that the Pocket instrument may be used to give a rough indication of the impurity of polluted air. The manner of using it for this purpose is as follows:—First, turn the stopcock K a quarter turn to the left, and draw down the piston. This takes the impure air into the cylinder. The whole of this air is then discharged by pushing the piston to the top of its stroke. By these movements nearly, but not quite, all the impure air is expelled from the cylinder. The small passage between the stopcock and the piston is still full of impure air. Immediately on pushing the piston to the top of its stroke, the stopcock is returned to its original position; the piston is then drawn down, and at once returned to its top position. By these movements we have taken some of the pure air out of the receiver and mixed it with the small amount of impure air in the pump passage, and the return stroke has sent the mixture into the receiver, where after being stirred, a shower is produced, and the drops counted.

This cannot give a very accurate result, as some of the particles must be lost when the air is drawn in from the receiver to mix with the impure air in the pump passage. This loss, however, does not seem to be great, owing probably to the higher temperature of the pump-barrel, from contact with the hands, preventing condensation. Owing to the possibility of some air being left between the top of the piston and the cylinder, it would be difficult to

gauge by measurement the capacity of the space not emptied, when the piston of the pump is returned, to enable us to make the necessary calculations to find the number of particles. Perhaps the best way of gauging would be to test air which gave, say, five drops per square millimetre, when using $\frac{1}{50}$ of impure air, and working in the usual way. Then test this same air and see how many it gave when using the contents of the small space above the piston. Perhaps it might give one drop per four square millimetres. If a series of tests give these figures as the average number, we would know that the capacity of the space was $\frac{1}{20}$ of the $\frac{1}{50}$ measure, or the $\frac{1}{1000}$ of that of the receiver. So that whatever number we observed in the air of the receiver when working in this manner would require to be multiplied by 1000 to get the number in the air tested.

The instrument is so constructed, that when the different parts are unscrewed they fit into a case $4\frac{3}{8}$ inches by $2\frac{1}{2}$ inches by $1\frac{1}{4}$ inches deep, or little larger than a well-filled cigar-case. The weight of the instrument, without the case, is a little under 8 oz.

On the Action of Metallic (and other) Salts on Carbonate of Lime. By Robert Irvine, F.C.S., and W. S. Anderson.

(Read January 9, 1891.)

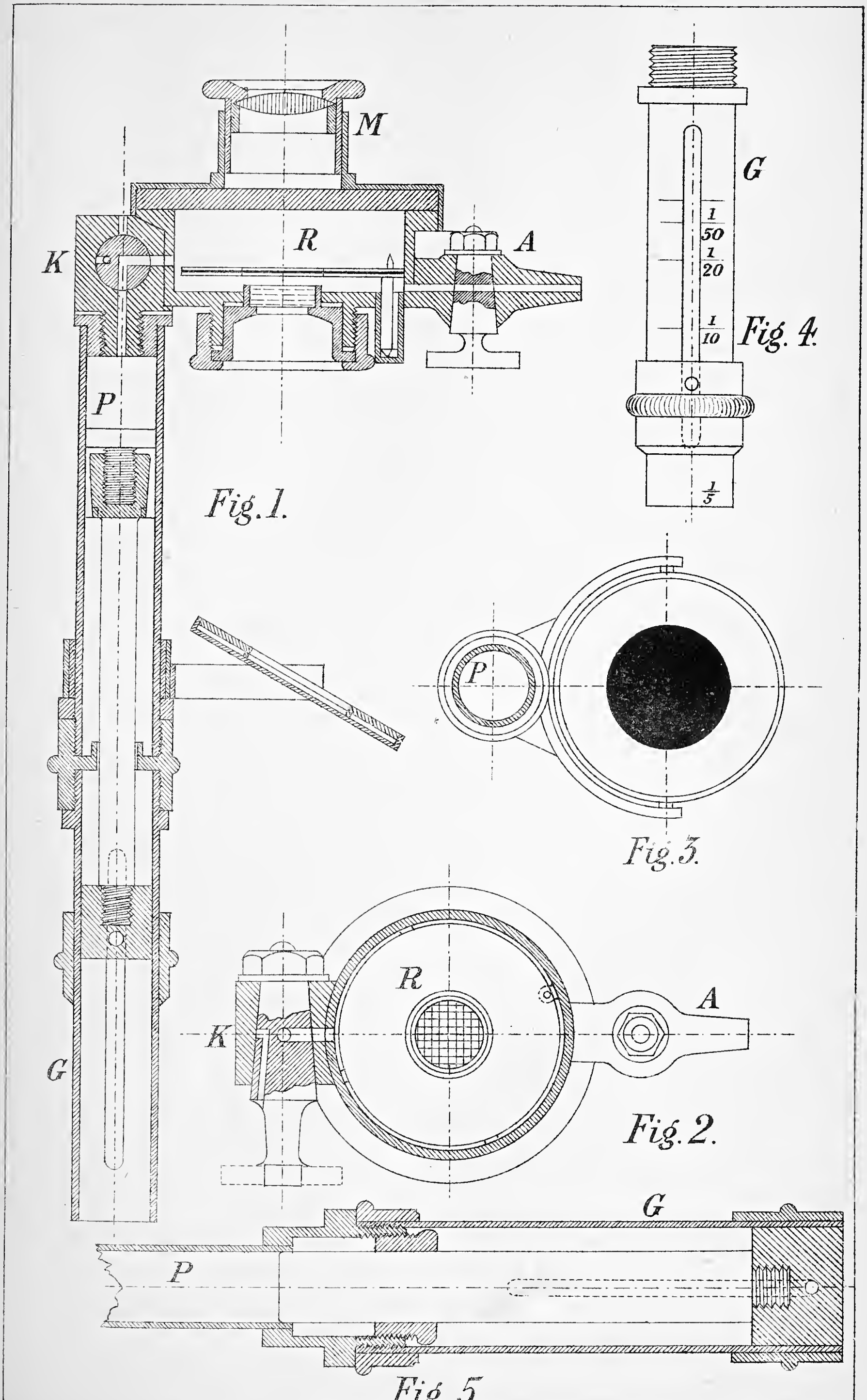
It is well known that pseudomorphic changes take place with many minerals. These changes may be either by alteration or displacement. In the case of carbonate of lime they are generally of the former order.

Among other work conducted at the Marine Station, Granton, during the past year, a number of experiments were instituted with the view of showing how far carbonate of lime was influenced in this direction by metallic and other salts.

Corals, preferably the more porous and soft varieties, were selected for this purpose, and these were exposed to the action of solutions of the following salts:—Chloride of manganese, sulphate of iron, chloride of zinc, chloride of chromium, nitrate of nickel, nitrate of cobalt, nitrate of copper, nitrate of lead, chloride of mercury, chloride of tin, nitrate of silver, phosphate of ammonia.

In many cases the action was very slow, especially in the case of

MR. JOHN AITKEN ON POCKET DUST-COUNTER.



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the salts of nickel and cobalt. On the other hand, with salts of copper and manganese, the action was sufficiently rapid so as to make a material difference, within a few weeks, in the composition of the coral exposed to their action.

In most cases there is a direct interchange between the lime (of the carbonate of lime) and the oxide of the metal which takes its place. Thus we have :—

1. With a copper salt, in seven months, 26·4 per cent. of carbonate of copper taking the place of an equivalent amount of carbonate of lime.
2. With chloride of manganese, in twelve months, 58·4 per cent. of carbonate of manganese.
3. With salts of iron practically the whole coral is altered—first, into carbonate, and ultimately, on exposure to air, into sesquioxide of iron.
4. With salts of zinc, 26·8 per cent. of carbonate of zinc had formed in six months.
5. With phosphate of ammonia the transference was between the carbonic acid of the coral and the ammonia of the salt. The lime having combined with the phosphoric acid to an extent equal to 60 per cent. of phosphate of lime.

Without doubt, phosphate of lime deposits, especially those found on old coral islands, have had their origin in this manner, the phosphoric acid being derived from the excreta of wild fowl, deposited upon dead coral or carbonate of lime, the amount of pseudomorphic change being in accordance with the quantity of guano deposited. Of course, transference between carbonate of lime and alkaline phosphates can only take place in the presence of water, so that we have no such pseudomorphs where the climate is rainless ; there the guano remains as deposited, whilst these deposits in rainy zones always assume the form of insoluble phosphate of lime.

Carbonate of lime, with silver and mercury salts, seems to throw down oxides, not carbonates. But the compounds with nickel and cobalt we have, as yet, been unable to determine.

With a true pseudomorph, the structural form of the carbonate of lime, be it in the shape of *coral*, *shells*, or *calcite*, remains

unchanged; when, however, an oxide is produced, as in the case with tin and mercury salts, it forms merely a superficial coating.

From the results of numerous experiments, which it is unnecessary to record here, we have good grounds for assuming that carbonate of lime, either in a massive or comminuted condition, or in solution, carries out the most important function of withdrawing metallic and other bodies from sea-water, which may be said to hold (often in minute amount) almost every elementary substance in solution, and fixing these in a concentrated condition.

The geological significance attaching to this property of carbonate of lime is apparent, as, without question, many metallic ores owe their origin to this source.

Manganese Deposits in Marine Muds. By Robert Irvine, F.C.S., and John Gibson, Ph.D.

(Read January 9, 1891.)

Two theories have been put forward in order to explain the formation of manganese deposits in marine muds, and more particularly with regard to manganese nodules: one by Murray, in a paper read before this Society in 1876, the other by Buchanan in 1888. Murray assumes the gradual oxidation of carbonate of manganese resulting ultimately in the formation of hydrated peroxide of manganese. Buchanan first propounded his theory in 1880, and subsequently, in a paper read before this Society in December 1890, argues as follows:—

"The principal agent in the comminution of the mineral matter found at the bottom of both deep and shallow seas and oceans is the ground fauna of the sea, which depends for its subsistence on the organic matter which it can extract from the mud.

"In order to fit them for collecting their nutriment in this way, the animals have been fitted with different forms of masticating or milling apparatus, so as to thoroughly deal with the matter which they pass through their bodies. It has been shown that most silicates are decomposed to a certain extent when ground or pulverised under water; so that the mere mastication of the sand or mud in presence of pure water would have a decomposing action on

the silicates which it contains. This action is much assisted, in the case of marine animals, by the fact that the water which they pass through their bodies along with the sand is charged with sulphates. These are easily reduced to sulphides by the action of the organic matter of the secretions of the animals. The resulting sulphide at once suffers double decomposition with any oxide of iron or manganese which is present as such in the mud, or may be being set at liberty from silicates under the decomposing influence of trituration under water. The sulphides of manganese and iron so formed are, in course of nature, extruded by the animals, and if exposed to the sea-water on the surface of the mud are quickly oxidised, the manganese taking priority. The mud below the surface layer, where ground life is abundant, remains blue, being protected by the oxidation of what is above it.

"At the bottom of the ocean the mineral matter is thus exposed to a reducing process due to the life of the animals which inhabit it, and to an oxidising process due to the oxygen dissolved in the water. Other things being equal, the redness or blueness of a mud or clay depends on the relative activity of these processes. They also require a controlling or modifying influence on one another. For, although marine animals are much less sensitive to variations in the amount of oxygen in their atmosphere than terrestrial animals, it is certain that there must be a limit to the deficiency of oxygen which each animal can support; and when this limit is approached, its reducing activity is diminished, or it may be extinguished. The water in the course of circulation is being continually renewed, and, meeting with a diminished amount of freshly-reduced matter, it is able to push the oxidation of the mud to a greater depth. It is easily conceivable that in many of the deep parts of the ocean the amount of ground life may be so limited that the water has no difficulty in oxidising at once its ejecta; and these conditions would be favourable to the formation of a red clay or chocolate mud, according to the preponderance of iron or manganese."

In a word, that the animals passing sand or mud through their bodies with sea-water tend to reduce the sulphates present in the sea-water, and the alkaline sulphides so formed cause the formation

of sulphides of iron and manganese, which, on subsequent exposure to sea-water containing oxygen, are quickly oxidised—the manganese taking priority.

It is obvious that any conclusion as to the relative correctness of these two theories cannot be arrived at solely by chemical considerations, but must depend largely upon such questions as the relative abundance and distribution of animal life upon the sea-floor; and, further, upon the physical structure of the deposits.

In this paper we propose to confine ourselves chiefly to the chemical aspect of the subject, and more particularly to certain reactions of manganese, which we believe to have a very direct bearing upon it.

A.—Behaviour of Hydrated Protoxide of Manganese.

If freshly-precipitated hydrated protoxide of manganese be added to sea-water, it is pretty freely dissolved, and if the sea-water be in large excess, the manganese remains in solutions for a very considerable time. If, however, more hydrated protoxide of manganese be added than is sufficient to form carbonate of manganese with the carbonic acid in the sea-water, the excess of manganese is precipitated, after a comparatively short period, as hydrated oxide of manganese (more or less completely peroxidised), provided the water is sufficiently ærated.

B.—Behaviour of Carbonate of Manganese.

Carbonate of manganese, when freshly precipitated and amorphous, dissolves in sea-water in notable quantity, but is very sparingly soluble in the crystalline form. Further, when carbonate of manganese is dissolved in sea-water, it remains in solution. Such solutions do not give rise to any rapid production of peroxide of manganese. This is in accordance with what has been hitherto ascertained concerning the behaviour of carbonate of manganese, which, as has been shown by Bischoff and others, is very slowly oxidised under ordinary circumstances. A. Gorgeu (*Comptes Rendus*, cviii. 1006–1009) states "that native manganese carbonate or diallogite is very stable, and remains unaltered after contact with ærated water for three years. Precipitated manganese

carbonate, which has become crystalline, remains in contact with ærated water, at an ordinary temperature, without any peroxide. If the precipitated carbonate remains in contact with ærated water for ten years about one-third is decomposed, and the product has the composition MnO,MnO_2. Two specimens, containing respectively eighty and seventy per cent. of manganese carbonate, were exposed to air in the dry state for eight years. In the first case thirty-three per cent., and in the second fourteen per cent., of manganese carbonate remained—the rest being converted into "the oxide MnO,MnO_2." Other observers have found that under certain conditions, and notably in presence of carbonate of lime, peroxidation takes place, although very slowly. This is in accordance with our own experience. Some eighteen months ago, in connection with Irvine and Anderson's investigation on the action of metallic salts on carbonate of lime,* some pieces of coral and chalk were placed in a weak solution of chloride of manganese in sea-water. Interchange has taken place, and fully fifty per cent. of the calcium has been replaced by the manganese. The outer portion of the coral is blackened, owing to the peroxidation of the carbonate, and the bottle in which the coral was placed has become covered with a film of peroxide of manganese. There is also a distinct precipitation of peroxide in the liquid.

C.—Behaviour of Sulphide of Manganese.

Precipitated sulphide of manganese in a moist condition is well known to be very unstable in presence of oxygen or air, and rapidly becomes brown owing to peroxidation. It also behaves like an alkaline sulphide towards certain metallic salts, and even gives up its sulphur to ferric hydrate, as was found by Buchanan (see his paper read before this Society, December 1890). In the presence, however, of carbonic acid sulphide of manganese is quickly and completely decomposed—sulphuretted hydrogen being given off and carbonate of manganese formed. This decomposition of sulphide of manganese takes place even when the carbonic acid is loosely combined, as in solution of bicarbonate of lime or manganese. Further, in the presence of carbonate of lime and oxygenated sea-

* *Proc. Roy. Soc. Edin.*, vol. xvi., p. 319.

water, sulphide of manganese is not peroxidised, carbonate of manganese and sulphate of lime being formed. This is shown by the following experiment:—Equivalent proportions of sulphide of manganese and precipitated carbonate of lime were added to sea-water, and a current of air was passed through the mixture for twelve hours. The mixture did not become brown, and when examined it was found that the whole of the manganese had been converted into carbonate, and the lime into sulphate. A similar quantity of sulphide of manganese to that used in the above experiment was mixed with distilled water and exposed to the action of a current of air for a like period. It became brown, and instead of giving off sulphuretted hydrogen on addition of hydrochloric acid, chlorine was evolved, so that the decomposition of the sulphide by oxidation was in this case evidently complete.

We find, further, that when sulphide of manganese is added to sea-water, in quantity not more than sufficient to form carbonate of manganese with all the carbonic acid present in the sea-water, the sulphide is completely decomposed, sulphuretted hydrogen liberated, and the manganese dissolved.

These facts appeared to us to be incompatible with the theory of the formation of manganese deposits propounded by Buchanan, which hitherto had appeared to us to offer a very plausible and probable explanation of many of the points connected with these curious formations.

In this change of view we were confirmed by the following experiment:—

A mixture of ferrous and manganous carbonates was added to sea-water along with a quantity of decomposing mussel flesh, and the whole mass allowed to decompose, air being excluded. After four or five days the contents of the vessel became black, and sulphuretted hydrogen was freely evolved. Air was then blown for twelve hours through a portion of the mixture, which was then filtered and carefully washed. The residue left in the filter was then examined for manganese, which was found to be entirely absent. Another portion of the decomposing mixture was examined for sulphide of iron. The whole of the iron which had been added as carbonate was found in the form of sulphide.

From the behaviour of manganese as above described, we have come to the conclusion that the formation of sulphide of manganese cannot be a result of the animal life, or the decomposition of animal matter at the sea-bottom, as supposed by Buchanan; inasmuch as sea-water containing excess of carbonic acid must be always present. Buchanan does not give any evidence whatever to show that sulphide of manganese is formed, but appears to rely upon the supposed analogy in the behaviour of iron and manganese. Under conditions such as those referred to by him, sulphide of iron is necessarily formed. Unlike sulphide of manganese, sulphide of iron is readily formed in the presence of sea-water, whether mixed with carbonate of lime or not, and solutions of carbonic acid or bicarbonates do not decompose it or prevent its formation.

Thus in all cases where, through the life processes of animals, sulphide of iron is formed as a result of the reduction of sulphates, the excess of carbonic acid necessarily formed at the same time must prevent the formation of sulphide of manganese.

This holds equally in the case of the decomposition of the dead bodies of animals at the sea-bottom.

On a Difference between the Diurnal Barometric Curves at Greenwich and at Kew. By Alexander Buchan, LL.D.

(Read June 16, 1890.)

In the "Challenger" Report on atmospherical circulation, the diurnal barometric curves at Gries and Klagenfurt in the Tyrol, and at Cordova in the Argentine Republic, are specially examined.

The most noticeable feature of these daily barometric oscillations is their very large amounts, those at Gries, for example, though in lat. 46° 30′ N., being quite tropical in amount; and the singular circumstance is that in no season does the morning minimum fall so low as the daily mean. Gries, Klagenfurt, and Cordova are each situated in a deep valley. In such situations, during night, the whole surface of the region is cooled by radiation below the air above it, and the air in immediate contact with the ground becoming

also cooled, a system of descending air-currents sets in over the whole face of the country bounding the deep valley. The direction and velocity of these descending currents are modified by the irregularities of the ground, and, like currents of water, they converge in the bottom of the valleys, which they fill to a considerable height with the cold air they bring down from the sides of the mountains. This cold and relatively dense air rises above the barometers which happen to be down in the valley, with the result that a higher mean pressure is maintained during the night. In summer, when the daily range of temperature reaches the maximum, the pressure during the coldest time of the night is maintained 0·040 inch higher at Gries than it is in open situations in that part of Europe. On the other hand, during the day these deep valleys become highly heated by the sun, and a strong ascending current of air is thereby formed, under which pressure falls unusually low. Thus, while at Vienna the afternoon minimum falls 0·026 inch below the daily mean, at Gries the amount of the fall is 0·058 inch, and at Cordova 0·061 inch.

The general result is, that in these deep valleys atmospheric pressure stands much higher during the night and falls much lower during the day than is elsewhere the case. The amounts increase in proportion to the daily range of temperature; or, strictly speaking, to the amounts the temperature falls below the daily mean during the night, and rises above it during the day. The object of this paper is to show that the same rule holds in comparatively shallow valleys such as that of the Thames.

Mr Francis C. Bayard has calculated, for the five years 1876–80, the diurnal range of barometric pressure for nine stations in the British Islands, including the two Observatories at Greenwich and Kew. The paper has recently been published by the Meteorological Council, in which the Tables give the diurnal range to the ten-thousandths of an inch. The diurnal range for these two places, which are only seven miles apart, being for the same five years, are therefore strictly comparable, and the fourth decimal renders possible a more exact comparison of the results.

The following are the departures from the daily means at Greenwich and Kew for June, from 9 A.M. to NOON, in ten-thousandths of an inch:—

	Greenwich.	Kew.	Difference.
7 A.M.	+59	+79	20
8 „	+85	+99	14
9 „	+87	+87	0
10 „	+91	+67	−24
11 „	+67	+45	−22
NOON.	+17	− 7	−24

This comparison has been made for the whole year, and the differences are entered in their places in the accompanying Table, where the minus sign indicates that, at the hour specified, Kew was that amount relatively lower with respect to its daily mean than Greenwich was with respect to its daily mean, and the plus sign that it was relatively higher.

A longer period of comparison between these two barometers than five years will doubtless give still smoother curves than the Table indicates. Meantime, it is very evident that the ordinary diurnal barometric curve at Kew has superimposed on it a strongly marked curve, due to the relatively low position of the Observatory in the valley of the Thames.

Table showing Comparison of Kew and Greenwich Barometers in Ten-thousandths of an Inch.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1 A.M.	− 2	0	+11	+ 6	+ 5	+28	+17	+ 8	+ 9	− 2	− 5	− 2	+ 6
2 „	0	− 1	+ 8	+ 6	+13	+26	+24	+18	+14	+ 3	− 7	+ 8	+10
3 „	+ 2	− 3	+ 5	+ 3	+11	+28	+25	+20	+19	− 7	−12	0	+ 8
4 „	+ 2	−12	+ 9	+ 5	+ 9	+24	+21	+30	+13	+15	− 7	−11	+ 8
5 „	− 5	−13	− 3	− 1	+17	+26	+23	+15	+ 8	+ 7	− 6	−14	+ 5
6 „	− 7	−13	− 3	+ 7	+22	+30	+29	+28	+21	+14	− 1	− 3	+11
7 „	− 9	− 1	− 5	0	+22	+20	+24	+15	+11	− 1	− 3	− 5	+ 5
8 „	−10	+11	− 8	− 1	+16	+14	+18	+15	+ 9	+ 3	+10	1	+ 8
9 „	−15	+11	+ 3	− 3	+ 6	0	+ 5	+ 1	+ 7	+ 7	+ 6	13	+ 1
10 „	− 1	+ 7	+11	−11	−10	−24	− 8	− 5	− 5	− 9	+ 8	+ 4	− 4
11 „	+ 1	+13	+ 7	− 8	−13	−22	−16	−10	+13	+ 1	+ 9	+ 8	− 1
NOON.	+12	+ 3	− 9	−18	−23	−24	−16	− 7	+ 3	− 3	− 4	− 8	− 6
1 P.M.	+ 6	+ 5	− 9	−10	−17	−16	−18	−16	− 1	− 3	− 5	+ 2	− 7
2 „	−18	−15	−27	−36	−45	−38	−36	−27	−17	− 9	−10	−16	−25
3 „	−17	− 7	−13	−12	−33	−26	−20	−22	−23	−11	−15	−12	−18
4 „	−15	− 9	−15	−21	−36	−36	−34	−33	−29	− 5	− 8	− 4	−20
5 „	−17	− 7	− 9	−19	−24	−28	−23	−35	−17	−11	−10	−12	−19
6 „	+10	+ 1	−17	− 5	−18	−24	−28	−25	−17	− 7	− 2	− 1	−12
7 „	+ 5	+ 3	− 3	+16	− 2	−16	−24	−11	−17	− 3	+ 9	+ 5	− 4
8 „	+17	+11	+ 5	+23	+14	+ 8	− 1	− 2	− 1	+ 8	+19	+ 9	+ 8
9 „	+17	+11	+11	+23	+15	+ 6	+ 3	− 3	− 4	+ 5	+10	+22	+ 9
10 „	+18	+ 8	+11	+27	+25	+10	+ 9	+ 8	+11	+ 5	+15	+17	+12
11 „	+12	+ 3	+13	+ 5	+21	+10	+13	+10	− 1	− 1	+ 8	+10	+ 8
MIDNIGHT.	+ 2	+ 7	+12	+ 8	+15	+16	+14	+ 8	+ 2	+13	+11	+16	+ 9

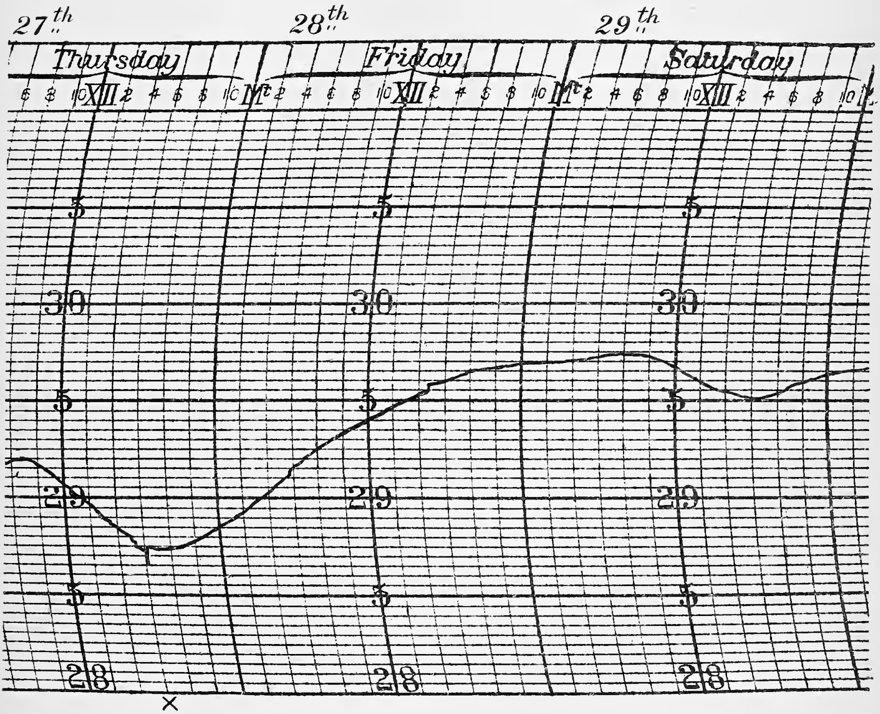
Barographic Record in the Vicinity of a Tornado. By **John Anderson.** *Communicated by* Dr BUCHAN. (With a Plate.)

(Read June 2, 1890.)

The fluctuation shown by the barographic record occurred immediately after 6 P.M., at the time of the passage of the tornado of Thursday, March 27, 1890, near Owensboro, Davies County, Kentucky. The distance of the barograph from the nearest point of the tornado can be approximated by the evidences of damage the tornado left, and did not exceed a mile and a quarter or a mile and a half. At this distance to the south-east of Owensboro there is a ridge 150 or 200 feet high, and a large brick house on top was unroofed and partially demolished. This is the first evidence of destruction in the vicinity of Owensboro, but previous to this the noise of the approaching tornado was plainly audible to persons on the streets of the town. Until reaching the ridge above mentioned, the tornado appears to have passed in the air, accompanied by a roaring sound, without doing any damage in its passage. From a point about twelve miles to the south-west a tornado passed over the latter city two hours later. The rate of progress of the cyclonic area of low pressure, as shown by the signal service map, was forty miles an hour. On the same day a parallel tornado passed about thirty miles to the south of Owensboro, near south Carrolton. There was none to the northwards.

The sudden dip in the barometric curve at 6 P.M. of March 27th is shown on the accompanying Plate. Though the centre of the tornado was from a mile and a quarter to a mile and a half distant, yet the barometer fell suddenly about the tenth of an inch, and immediately thereafter rose as suddenly to a point nearly two-hundredths of an inch higher than the point from which it fell. This observation, which is new to science, gives the explanation of the wrecking of buildings by tornados as by an explosive force within the buildings. The sudden lowering of the pressure outside, which must greatly exceed the tenth of an inch near the centre of the tornado, is amply sufficient to account for the fearful energy developed in these tempests.

Diagram Shewing the Barometric Curve at Owensboro', Kentucky, during March 27th, 28th, and 29th, 1890. The X indicates the hour of occurrence of the Sudden Dip of the Barometer when the Centre of the Tornado passed near the Station.



Note on Potassium Persulphate.

By **Hugh Marshall**, D.Sc.

(Read February 16, 1891.)

Persulphuric anhydride and the corresponding acid have been known for some time. Berthelot obtained the former by subjecting a mixture of sulphurous anhydride and oxygen to the *effluve électrique* (as in the preparation of ozone), and a mixture of the latter with sulphuric acid, by adding the anhydride to water. He also prepared a similar mixture by the electrolysis of sulphuric acid solution in a cell where the electrodes were separated by a porous pot. Both substances he found to be very easily decomposed, spontaneously evolving oxygen. Up till now, however, the corresponding salts have not been prepared. In fact, Mendeléef, while commenting on Berthelot's results, expresses the opinion that persulphuric anhydride is not a true acid-forming oxide, but a peroxide similar to those of the metals barium, lead, &c., and that Berthelot's persulphuric acid is analogous to peroxide of hydrogen. Recently, however, I have obtained the potassium salt, and have since succeeded in preparing it in quantity.

While oxidising a solution of cobaltous sulphate in presence of potassium sulphate and sulphuric acid, by electrolysing it in a divided cell, as in Berthelot's experiment, I obtained a quantity of white feathery crystals. These were filtered off, washed with cold water, and dried on porous plate over sulphuric acid. The substance was found to possess powerful oxidising properties. When heated it fused and soon decomposed, evolving acid fumes and leaving a white residue which proved to be potassium sulphate. A solution of the substance gave only a faint precipitate with barium chloride solution, but on boiling a dense precipitate of barium sulphate separated gradually while chlorine was simultaneously evolved. These properties seemed to point to the salt being a persulphate, and analysis confirmed this opinion.

A known quantity was ignited and the resulting sulphate of potassium weighed. The residue amounted to 64·2 per cent. of the original. For potassium persulphate theory requires 64·4. The

oxidising power was estimated by titration with ferrous sulphate and potassium permanganate. The extra oxygen thus found was 5·92 per cent. (equal to 35·5 of SO_4). Theory requires 5·93 (35·6 of SO_4).

I have since prepared a considerable quantity of the salt by electrolysing a solution of potassium hydrogen sulphate in a divided cell. After some hours the persulphate crystallises out from the liquid surrounding the anode.

Potassium persulphate dissolves fairly readily in water at the ordinary temperature, easily in hot water. If the solution be boiled, especially if it is acid, decomposition with evolution of oxygen occurs. By solution in warm water, and cooling, the salt can be recrystallised in prisms resembling those of potassium permanganate, with which the persulphate is evidently isomorphous.

Dr James Walker has kindly determined the electric conductivity of the solution, and his results show that the formula is KSO_4, the solution behaving in a manner comparable to one of potassium perchlorate (which is also isomorphous with the permanganate).

The solution of the pure salt is neutral to litmus, and appears to be stable at ordinary temperatures. It gives no precipitate with solution of barium salt. With silver nitrate it gives no immediate precipitate, but what appears to be silver peroxide separates out on standing. When mixed with potassium iodide solution, iodine is liberated only gradually, but more quickly on heating. The solution is not decomposed by peroxide of hydrogen. It is attacked by ferrous sulphate in the cold, ferric and potassium sulphates being produced. If some of the solid substance be added to a small quantity of strong ferrous sulphate solution, as the salt dissolves the green colour changes to brown, and the liquid becomes warm.

When the solid is gently warmed with strong nitric or sulphuric acid, oxygen highly charged with ozone is evolved. Hydrochloric acid gives chlorine.

The properties of the salt have been as yet but superficially examined, and no attempt has been made to prepare other persulphates. I am, however, engaged in a fuller investigation of the subject, and also in examining the behaviour of salts of other acids when electrolysed in a divided cell.

On the Soaring of Birds: *being a Communication from* Mr R. E. Froude *in continuation of the Extract from a Letter by the late* Mr William Froude *to* Sir William Thomson, *published in these "Proceedings," March* 19, 1888.

(Read January 5, 1891.)

The object of the present communication is to give the purport of the remainder of the letter referred to in the title, as well as that of other letters bearing on the same subject written by the late Mr Froude shortly afterwards, which were not at hand at the time the extract referred to was printed.

In the extract already printed, Mr Froude expressed the view that the continued "soaring" (or "sailing flight," as it has also been called) of birds only took place where there was an ascending current of air of sufficient speed. And he noticed as an apparent exception, which he had observed one day on the passage to the Cape on board H.M.S. "Boadicea," that in a very light wind some albatrosses were seen soaring (manifestly without wing stroke) "almost *ad libitum*," where there could not possibly be any ascending current due to deflection of wind by the ship. He suggested as a possible explanation, and one which to all appearance fairly accorded with the birds' visible movements, that they were availing themselves of the ascending stratum of air which must have extended above the advancing slope of each wave of the well-marked ground-swell which was running. From the dimensions of this, the maximum upward speed of such air current was estimated at about 3 feet per second.

Thus far the extract already printed. In the original letter there followed a mathematical investigation to determine whether this upward air current of 3 feet per second could suffice for the supposed effect. This I now paraphrase and somewhat abbreviate as follows:—

Suppose a bird soaring with constant speed and direction in still, or uniformly moving, air; and let

$\alpha =$ the angle (taken downwards from horizontal, in a fore and aft vertical plane) of the wing surface; and,

$\alpha + \sigma =$ that (similarly taken) of the direction of motion through the air. Hence,

$\sigma =$ the angle of the wing surface with the line of motion.

The nett force acting upon the bird, owing to its motion through the air, should be treated as consisting of two elements, viz. (1) the normal force on the wings due to their obliquity σ to the line of motion, (2) the resistance due to the air friction on the wing surfaces and body. Taking, then,

$A =$ total wing surface (one side); sq. ft.
$rA =$ total surface area as reckoned for computing resistance; do.
$V =$ speed through the air; ft. per. sec.

These two elements of force may be expressed thus—

Normal force (lbs.) $= PAV^2\sigma$,
Resistance (do.) $= FrAV^2$,

[where P and F are constants appropriate to the resisting medium, in this case air].

The strict condition of equilibrium for constant speed and direction is that the resultant of these forces should be vertical, and equal to the weight of the bird. Seeing that the values for α and σ with which we have to deal are small, this condition is defined with sufficient approximation for our purpose by the equations—

$$W\alpha = FrAV^2; \text{ whence } \alpha = \frac{FrAV^2}{W}; \quad . \quad . \quad (1)$$

$$W = PAV^2\sigma; \text{ whence } \sigma = \frac{W}{PAV^2}; \quad . \quad . \quad (2)$$

[where $W =$ weight of bird in lbs.].

In order that the soaring may take place without the bird losing level, the air must have an upward motion (or upward component of motion), the speed of which (with a similar approximation) may be expressed as—

$$= V(\alpha + \sigma),$$

$$= \frac{FrAV^3}{W} + \frac{W}{PAV}; \quad . \quad . \quad . \quad . \quad (3)$$

By equation (1), the speed V depends on the wing angle α, which the bird may regulate at his pleasure; and we will assume that he thus assigns such value to V ($=$ say V_1) as gives minimum value to $V(\alpha + \sigma)$. By differentiating equation (3), this value is determined as—

$$V_1 = \sqrt{\frac{W}{A}} \times \frac{1}{\sqrt[4]{3PFr}}, \left[= \cdot 76 \times \sqrt{\frac{W}{A}} \times \frac{1}{\sqrt[4]{PFr}} \right]; \qquad (4)$$

whence, by substituting in (1), (2), and (3), we get for the corresponding values of α, σ, &c., = say α_1, σ_1, &c., as follows :—

$$\alpha_1 = \sqrt{\frac{Fr}{3P}} = \cdot 577 \sqrt{\frac{Fr}{P}}; \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$\sigma_1 = \sqrt{\frac{3Fr}{P}} (= 3\alpha_1) = 1 \cdot 73 \sqrt{\frac{Fr}{P}}; \quad . \quad . \quad . \quad (6)$$

$$\alpha_1 + \sigma_1 (= 4\alpha_1) = 2 \cdot 31 \sqrt{\frac{Fr}{P}}; \quad . \quad . \quad . \quad . \quad (7)$$

$$V_1(\alpha_1 + \sigma_1) = 4\sqrt{\frac{W}{A}} \times \frac{(Fr)^{\frac{1}{4}}}{(3P)^{\frac{3}{4}}} = 1 \cdot 75 \sqrt{\frac{W}{A}} \times \frac{(Fr)^{\frac{1}{4}}}{P^{\frac{3}{4}}}; \quad . \quad (8)$$

Even without putting numerical values to the symbols, we may at once note some interesting conclusions which follow from the structure of these equations.

(1) The angle values α_1, σ_1, and $(\alpha_1 + \sigma_1)$, bear a constant ratio to one another, independent of the values assigned to F, P, r, A, or W.

(2) These absolute angle values depend solely on $\frac{Fr}{P}$, (in which F and P are constant for a given medium, and r dependent only on the proportions of the bird), and are independent of $\frac{W}{A}$, or weight per square foot of wing area.

(3) Hence, $\frac{W}{A}$ influences the value of $V_1(\alpha_1 + \sigma_1)$ only as influencing the speed.

(4) In similarly proportioned birds of different since since $\frac{W}{A}$ (or weight per square foot wing area) varies as dimension, $V_1(\alpha_1 + \sigma_1)$ varies as square root of dimension.

This expression, $V_1(\alpha_1 + \sigma_1)$, besides indicating the minimum speed of ascending air current necessary for soaring or quiescent flight, without loss of level, furnishes also a presumable measure of the minimum effort needed to sustain active flight in still air without loss of level. For in maintaining his level by active flight, the bird must be supplying at least the work theoretically equivalent to lifting his own weight at the rate at which he would quiescently

descend. And the work which can be done per time-unit by animals, when taxing their strength in given degree, is said, I believe, to bear in general a fairly constant proportion to their total weight; in other words, to be an approximate constant when stated in the form of the equivalent speed of lift of their own weight.

Hence conclusion (4) above is in accordance with the fact that the larger flying birds are comparatively few, and that the largest birds do not fly at all.

The value of this supposed approximate constant, viz., the speed at which animals in general are capable of continuously lifting their own weight for a long time at a stretch, if estimated from the reputed "horse-power" (or equally from the reputed man-power), would be about 30 ft. per minute, or ·5 ft. per second. If, then, the same relative power-capacity may be assigned to birds as we have estimated for the average animal, we might have concluded at the outset, and without the aid of the mathematical reasoning which has been given, that the upward air current of 3 ft. per second ascribed to the passage of the waves, would suffice several times over to enable any birds to soar that are able to fly in still air.

On the other hand, equation (8) above, if interpreted by any such numerical values as would be used in any ordinary mechanical problem of the kind, gives a value for $V_1(\alpha_1 + \sigma_1)$ much greater than 3 ft. per second, and we are thus confronted by a serious paradox.

Mr Froude took for his albatrosses $W = 20$ lbs., $A = 22$ square feet (figures presumably obtained from the officers of the ship).* For P, F, and r, he took (to minimise the paradox) as the most favourable values which he thought might be conceivably justified, $P = \frac{1}{217}$, $F = \frac{1}{245,000}$, $r = 1{\cdot}5$. These values for P and F are approximately the values fairly well established for water, multiplied by the specific gravity of air; F not increased on the score of the greater viscosity of air, but P *doubled* on the score of advantage that might con-

* These figures give $\frac{W}{A} = {\cdot}91$. Memoranda of Mr Froude's include weights and measurements afterwards obtained, which show much higher values. Recent measurements of my own of an albatross preserved in spirits at the Museum of Zoology, Cambridge, give $\frac{W}{A} = 2{\cdot}3$.

ceivably be derived from the curvature of the wing surface ;* also r is taken as 1·5, instead of over 2·0 as it *prima facie* should be, on the score of eddies conceivably annulling in part the friction on the upper surfaces of the wings. These values put into equation (8) give no less than 4·7 *feet per second* as the value for $V_1(\alpha_1 + \sigma_1)$. Thus, apparently—

(1) The formula as interpreted by these constants *requires no less* than 4·7 ft. per second rate of descent.

(2) The suggested explanation of the soaring *admits of no more* than 3 ft. per second.

(3) The fact that birds can sustain flight in still air *admits of very much less still*, unless we can suppose that in birds the relative power capacity is many times greater than it is in horses and men.

It is not my purpose here to attempt to clear up this paradox. Mr Froude appears to have considered the formula unimpeachable in structure, at least as a fair approximation (and so I think it evidently is), but the constants probably in error. At any rate, he seems to have treated the argument from the power capacity of animals as sufficient *prima facie* evidence that the updraught of the advancing wave slopes would suffice for soaring; because in subsequent letters he describes further observations made with the object of identifying the occasions of soaring in a calm with position of the bird over the advancing wave slopes. But first he had an opportunity of observing soaring in a strong wind, under circumstances which appeared to defy the idea that advantage was being taken of local ascending currents. This must be described in his own words, in a letter to myself dated 14th February 1879 :—

"But since I have been *here* we have had a lot of S.E. gales; and though the sea surface has been like that at Torquay pierhead in a S.S.W. gale, and thus without any big waves, we have seen a lot of *whale birds*, as they are called, playing the skim trick in the most marvellous and fascinating way.

"The *albatrosses* did occasionally *flap*, but these birds went high and went low, went fast and went slow, with the wind or against

* As a justification for this, Mr Froude suggests the circumstance that in the cup anemometer the circumferential speed of the cups is accounted to be $\frac{1}{3}$ the speed of the wind ; hence the relative speed of the wind facing the concave surfaces is only one-half that facing the convex surfaces, yet the wind presumably exerts the same force on both.

the wind, now hove to close to the water, and near enough to the ship for the most definite scrutiny, and then going ahead and upwards if they pleased, not flapping a wing once for hours, I may swear!—all in such a way as to be dumbfoundering, unless it be possible to suppose an ascending current apparently uniformly distributed over a level ocean, and reaching to at least 50 or 60 feet above it, and with a rate of ascent sufficient to explain the birds' behaviour. This supposition is *prima facie* an inadmissible one, for the air, if it was *all ascending*, would leave a vacuum over the water.

"At first I thought that the retarding action of the water friction (which was plainly enormous, for it was tearing the water surface to tatters) might explain the action by the circumstance that the retardation would *crumple* up the lower air strata endways, and by thickening them, would in effect produce an ascending motion in them.

"But in spite of the more vigorous frictional action close to the water surface, the ascent of the particles due to the crumpling up would be *nil* at the surface; yet the birds seemed to find the ascent as active *there* as anywhere. Still I think there is something in this view.

"Two days later, however, when the gale was a good bit more furious, I had a better proof of what was happening, though the 'how it happened' is still a puzzle.

"You know how in a heavy gale the sea surface seems to drift like *dust?* Well, in this case, the air was for a long time so full of sea spray up to a level of 50 or 60 feet, that it looked as if a heavy April shower was passing, though there was a clear blue sky overhead, and sunshine.

"Now, whatever could carry spray to that height would answer the birds' purpose. To-day the birds are again about, but the wind is only a double reef cutter breeze, if so much; and to-day, though they do a good deal of skimming, they have also to do a great deal of flapping at intervals."

As an explanation of the ascent of the particles of spray, Mr Froude goes on to suggest that the frictional eddies in the air must receive their most effective renewal of energy from the friction on their under sides nearest the water surface, and that consequently their

speed must be greater on the ascending side than on the descending side. The particles of spray passing across and through the vortices must be subjected alternately to the upward and downward forces due to the ascending and descending speeds. True, the ascending streams, being thinner in proportion as their speed is greater, will presumably act on the particles for a proportionately smaller share of the total time; but the resistance being as speed squared, the aggregate upward momentum imparted to the particles will nevertheless exceed the aggregate downward momentum.

This suggestion is interesting, as a plausible explanation of the phenomenon of the rising spray; at the same time I hardly think the suggested operation can favour the soaring of birds except by a second order quantity. For, in proportion as the bird's speed is high (as I think it must be), relatively to the speed of the eddies, the effect of the local contrarities of the eddy speeds becomes to the bird one simply of small differences in angle of impact on the wings; and, since the pressure on an obliquely moving plane varies simply as the angle (for small angles), the consequent differences in upward pressure would be proportional to the times for which those pressures act, so that the aggregate upward momentum and mean upward force would be the same as in still air.

I imagine that the soaring witnessed by Mr Froude on the occasion which he describes, is to be ascribed to an operation which, so far as I know, was first suggested by Lord Rayleigh in a communication to *Nature* of 5th April 1883, viz., a utilisation by the birds of the difference of wind-speed at different levels. But this explanation evidently did not occur to Mr Froude at the time, and I need make no further reference to it here.

Mr Froude's next letter bearing on the subject was dated Saldanha Bay, 24th February 1879, and in it he says :—

" . . . . . The voyage up from Simons Bay was delightful; for it was a glassy calm; and as there was also a tolerably pronounced swell, especially the latter part of the way, I was able (and Tower helped me) to watch the albatross's flight in a calm, with the following results :—When flying high they had to flap their wings continuously, except when descending. When near the surface they 'skimmed' occasionally, and, as far as we could distinguish, they did this only when traversing a region over an ascending wave slope.

Very often this was conspicuous. Now and then I noticed one or more of the birds skimming for a half-moment at a time in a position which *must* have been so, viz., when they were hidden, or all but hidden, from us by a wave crest, the *back* or the descending side of which was towards the ship. As the waves were *long* and not high, it was only by keeping *exactly* in this position that a bird could remain invisible, or visible only partially and for a second or two at a time, as the wave varied in form a little, or as he rose and fell a little.

"It also frequently happened that two, three, or four of the birds were flying in close company, generally in single file. When they were thus flying close to the water, they occasionally 'skimmed,' and then after a few seconds began again to flap. And it was noticeable that they all made the change *simultaneously*, ... implying that they had simultaneously arrived at a suitable region."

At the end of a letter on other subjects, dated 10th March 1879, he says—"I have made quite sure that the *skimming birds* follow the ascending wave-slopes as I had surmised."

These remarks of Mr Froude seem to make it clear that the up-draught of the advancing slopes of a ground swell in a calm may sometimes be a cause of soaring. It certainly seems to be the only cause which can account for soaring in a calm or very light wind; on the other hand, it is a cause which can operate only when there is a large swell, and when the wind is either very light or not in the direction of the swell.

Perhaps the most interesting feature of the letters consists in the analysis of the theoretical conditions of flight, and the paradox which thence results. For this paradox has an important bearing on the computation of air resistances in general, and any information which may serve to throw light upon it has a correspondingly wide significance.

On some hitherto unproved Theorems in Determinants. By Thomas Muir, LL.D.

(Read January 19, 1891.)

Most of the theorems in question occur at the outset of a paper * by Professor Cayley, entitled, "Chapters on the Analytical Geometry of n Dimensions"; they constitute, in fact, Chapter I. The first theorem I should prefer, for the present, to enunciate as follows :—

If m *determinants of the* n^{th} *order all have the same* $n-1$ *columns in common, and all vanish, then every determinant of the* n^{th} *order whose* n *columns are chosen from the* $m+n-1$ *different columns must vanish likewise.*

Taking the case where $m=3$ and $n=4$, and where therefore we have

$$|a_1b_2c_3d_4| = |a_1b_2c_3d_5| = |a_1b_2c_3d_6| = 0 ,$$

we are required to show that the twelve other determinants of the 4th order formed from the array

$$\begin{array}{cccccc} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{array}$$

also vanish. To this end we note first that any two of the given three are connected with one of the twelve by a linear relation, in virtue of which the latter vanishes when the two former simultaneously vanish. If we write the first two in the shorter form $|1234|$, $|1235|$, the relation in question is

$$|1234|\,|1257| - |1235|\,|1247| + |1237|\,|1245| = 0 , \qquad \text{(A)}$$

7 being the suffix-number of any new arbitrary column. Interchanging 2 and 3 we have also

$$|1324|\,|1357| - |1325|\,|1347| + |1327|\,|1345| = 0 , \qquad \text{(A}')$$

and interchanging 1 and 2 in this we have

$$|2314|\,|2357| - |2315|\,|2347| + |2317|\,|2345| = 0 . \qquad \text{(A}'')$$

* *Cambridge Mathematical Journal*, vol. iv. pp. 119–127; or, *Collected Math. Papers*, vol. i. pp. 55–62.

It is thus seen that the vanishing of $|1234|$ and $|1235|$ entails the vanishing of $|1245|$, $|1345|$, $|2345|$. Similarly from the vanishing of $|1234|$ and $|1236|$ we infer the vanishing of $|1246$, $|1346|$, $|2346|$; and from the vanishing of $|1235|$ and $|1236|$ we infer the vanishing of $|1256|$, $|1356|$, $|2356|$.

In the next place all the three original determinants are connected with one of the twelve by a linear relation, and from this like consequences ensue. The relation is

$$|1234|\,|1567| - |1235|\,|1467| + |1236|\,|1457| - |1237|\,|1456| = 0, \quad (\mathrm{B})$$

from which by interchange as before we have also

$$|2134|\,|2567| - |2135|\,|2467| + |2136|\,|2457| - |2137|\,|2456| = 0, \quad (\mathrm{B}')$$

$$|3214|\,|3567| - |3215|\,|3467| + |3216|\,|3457| - |3217|\,|3456| = 0. \quad (\mathrm{B}'')$$

It is thus seen that the vanishing of $|1234|$, $|1235|$, $|1236|$ entails the vanishing of $|1456|$, $|2456|$, $|3456|$, which are the last three determinants of the twelve.

The identities (A) and (B) have long been known; the one is an extensional of

$$|34|\,|57| - |35|\,|47| + |37|\,|45| = 0,$$

and the other an extensional of

$$|234|\,|567| - |235|\,|467| + |236|\,|457| - |237|\,|456| = 0.$$

These are the first two cases of a general theorem discovered and brought into notice by Sylvester, but included in a wider generalisation of earlier date. Had the determinants with which we started been of a higher order than the 4th, we might have required to use the next case, viz., the extensional of

$$|2345|\,|6789| - |2346|\,|5789| + |2347|\,|5689| - |2348|\,|5679| + |2349|\,|5678| = 0.$$

Cayley's mode of enunciation is :—The 15 (*i.e.*, $C_{6,4}$) equations

$$\left\|\begin{matrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{matrix}\right\| \doteq 0.$$

are not independent, but are reducible to 3; and if these be

$$(1)=0, \quad (2)=0, \quad (3)=0,$$

then any one of the twelve other determinants is expressible in the form

$$\theta_1(1) + \theta_2(2) + \theta_3(3).$$

The above demonstration has the advantage of showing what θ_1, θ_2, θ_3 are in every case.

There is, however, quite a different mode of viewing and investigating the theorem. The identities (A), (A′), (A″), (B), (B′), (B″) may each be looked on as furnishing the result of an elimination. For example, having used (A) to prove that if $|1234| = 0$ and $|1235| = 0$ then $|1245| = 0$, we may manifestly view the work thus accomplished as the elimination of the suffix 3 from the given equations. The question consequently arises, May the demonstration not be presented in the form of an ordinary process of elimination?

Writing the first given equation in the form

$$a_1|b_2c_3d_4| - a_2|b_1c_3d_4| + a_3|b_1c_2d_4| - a_4|b_1c_2d_3| = 0,$$

and the second in a similar manner,

$$a_1|b_2c_3d_5| - a_2|b_1c_3d_5| + a_3|b_1c_2d_5| - a_5|b_1c_2d_3| = 0,$$

and from these eliminating a_3 we have

$$\begin{aligned} &a_1\{-|b_1c_2d_5|\,|b_2c_3d_4| + |b_1c_2d_4|\,|b_2c_3d_5|\} \\ &-a_2\{-|b_1c_2d_5|\,|b_1c_3d_4| + |b_1c_2d_4|\,|b_1c_3d_5|\} \\ &+a_4\{|b_1c_2d_5|\,|b_1c_2d_3|\} \\ &-a_5\{|b_1c_2d_4|\,|b_1c_2d_3|\} \qquad\qquad = 0, \end{aligned}$$

from which, on striking out the common factor $|b_1c_2d_3|$, there results

$$a_1|b_2c_4d_5| - a_2|b_1c_4d_5| + a_4|b_1c_2d_5| - a_5|b_1c_2d_4| = 0,$$

$$i.e. \qquad |a_1b_2c_4d_5| = 0.$$

Turning now to (B), and observing that the result there obtained is the elimination of the suffixes 2, 3 from the equations $|1234| = 0$, $|1235| = 0$, $|1236| = 0$, we write the said equations in the form

$$\left.\begin{aligned} a_1|b_2c_3d_4| - a_2|b_1c_3d_4| + a_3|b_1c_2d_4| - a_4|b_1c_2d_3| &= 0, \\ a_1|b_2c_3d_5| - a_2|b_1c_3d_5| + a_3|b_1c_2d_5| - a_5|b_1c_2d_3| &= 0, \\ a_1|b_2c_3d_6| - a_2|b_1c_3d_6| + a_3|b_1c_2d_6| - a_6|b_1c_2d_3| &= 0, \end{aligned}\right\}$$

and thence eliminate a_2, a_3. The result is

$$\begin{vmatrix} a_1|b_2c_3d_4| - a_4|b_1c_2d_3| & |b_1c_3d_4| & |b_1c_2d_4| \\ a_1|b_2c_3d_5| - a_5|b_1c_2d_3| & |b_1c_3d_5| & |b_1c_2d_5| \\ a_1|b_2c_3d_6| - a_6|b_1c_2d_3| & |b_1c_3d_6| & |b_1c_2d_6| \end{vmatrix} = 0 .$$

i.e.

$$\begin{vmatrix} |b_2c_3d_1| & \cdot & \cdot & a_1 \\ |b_2c_3d_4| & |b_1c_3d_4| & |b_1c_2d_4| & a_4 \\ |b_2c_3d_5| & |b_1c_3d_5| & |b_1c_2d_5| & a_5 \\ |b_2c_3d_6| & |b_1c_3d_6| & |b_1c_2d_6| & a_6 \end{vmatrix} = 0 ,$$

i.e.

$$\begin{vmatrix} \cdot & \cdot & \cdot & 1 \\ |b_1c_2| & -|b_1d_2| & |c_1d_2| & \cdot \\ |b_1c_3| & -|b_1d_3| & |c_1d_3| & \cdot \\ |b_2c_3| & -|b_2d_3| & |c_2d_3| & \cdot \end{vmatrix} \cdot \begin{vmatrix} d_1 & c_1 & b_1 & a_1 \\ d_4 & c_4 & b_4 & a_4 \\ d_5 & c_5 & b_5 & a_5 \\ d_6 & c_6 & b_6 & a_6 \end{vmatrix} = 0 ,$$

so that on dividing by $|b_1c_2d_3|^2$ we have

$$|a_1b_4c_5d_6| = 0 ,$$

as was to be proved.

Let us pass now from the determinants of the 4th order arising out of the rectangular array with which we commenced to the determinants of the same order arising out of the *square* array

$$\begin{matrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \\ e_1 & e_2 & e_3 & e_4 & e_5 & e_6 \\ f_1 & f_2 & f_3 & f_4 & f_5 & f_6 \end{matrix}$$

and let us inquire how many of these minors are independent. We know that the total number of them is $(C_{6,4})^2$, *i.e.*, 225, and that they constitute the elements of the 4th compound of $|a_1b_2c_3d_4e_5f_6|$. We see further that the first row of this compound determinant consists of the fifteen determinants dealt with above, and that therefore only three of the fifteen are independent. Similarly it follows that the vanishing of the first three of the second row entails the vanishing of all the rest of the row, and that the vanishing of the first three in the

third row entails like consequences. But the first three elements of the first three rows constitute likewise the first three elements of the first three columns; and the elements of a column are related to each other exactly as the elements of a row are; consequently the vanishing of these nine elements entails the vanishing of all the other elements of the first three columns. Finally, viewing these last elements as constituting the first three elements of the 4th and remaining rows, we see that all the 225 minors will vanish if the nine minors common to the first three rows and first three columns vanish.

Had the original determinant been of the n^{th} order and the minors formed from it been of the m^{th}, the compound determinant would have been of the order $C_{n,\,m,}$ and all the elements of its first row could have been shown to vanish if

$$0 = |1,2,3, \ldots, m-1, m| = |1,2,3, \ldots m-1, m+1| = \ldots = |1,2,3, \ldots m-1, n|,$$

that is to say, if $n-m+1$ of them vanished. The general theorem we have thus proved is—*All the minors of the* m^{th} *order formed from a determinant of the* n^{th} *order will vanish if* $(\mathrm{n}-\mathrm{m}+1)^2$ *of them vanish.*

If the original determinant be axisymmetric, the compound determinant is also axisymmetric, and therefore the said $(n-m+1)^2$ minors are not in this case all different. In fact, instead of there being $n-m+1$ different minors to be counted in each row, there is 1 less in the second row, 2 in the third, and so on, the total thus being only

$$(n-m+1)+(n-m)+(n-m-1)+\cdots+1\,.$$

i.e.

$$\tfrac{1}{2}(n-m+1)(n-m+2)\,.$$

This result was enunciated without proof by Sylvester in the *Philosophical Magazine* for September 1850. It appears from the foregoing to be an easy deduction from Cayley's theorem published seven years before.

Cayley's next theorem is bound up with a certain notation introduced by him, and forms indeed the fundamental justification for the use of the said notation. To indicate that all the 15 determinants of the 4th order formed from the array

$$\begin{matrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{matrix}$$

vanish, Cayley wrote

$$\left\| \begin{matrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{matrix} \right\| = 0\,;$$

and the theorem referred to is that if this group of equations holds it follows that the similar group got by the quasi-multiplication of both sides by the determinant $|\lambda_1\mu_2\nu_3\rho_4\sigma_5\tau_6|$ holds also; in other words, that so far as multiplication by $|\lambda_1\mu_2\nu_3\rho_4\sigma_5\tau_6|$ is concerned, we may view the rectangular array as if it denoted a single entity.

Taking the first of the fifteen determinants of the new group, viz.:

$$\left| \begin{matrix} \lambda_1 a_1 + \lambda_2 a_2 + \ldots + \lambda_6 a_6 & \mu_1 a_1 + \ldots + \mu_6 a_6 & \nu_1 a_1 + \ldots + \nu_6 a_6 & \rho_1 a_1 + \ldots + \rho_6 a_6 \\ \lambda_1 b_1 + \lambda_2 b_2 + \ldots + \lambda_6 b_6 & \mu_1 b_1 + \ldots + \mu_6 b_6 & \nu_1 b_1 + \ldots + \nu_6 b_6 & \rho_1 b_1 + \ldots + \rho_6 b_6 \\ \lambda_1 c_1 + \lambda_2 c_2 + \ldots + \lambda_6 c_6 & \mu_1 c_1 + \ldots + \mu_6 c_6 & \nu_1 c_1 + \ldots + \nu_6 c_6 & \rho_1 c_1 + \ldots + \rho_6 c_6 \\ \lambda_1 d_1 + \lambda_2 d_2 + \ldots + \lambda_6 d_6 & \mu_1 d_1 + \ldots + \mu_6 d_6 & \nu_1 d_1 + \ldots + \nu_6 d_6 & \rho_1 d_1 + \ldots + \rho_6 d_6 \end{matrix} \right| ,$$

we see that it is equal to the sum of products usually represented by

$$\left| \begin{matrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{matrix} \right| \cdot \left| \begin{matrix} \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 & \lambda_5 & \lambda_6 \\ \mu_1 & \mu_2 & \mu_3 & \mu_4 & \mu_5 & \mu_6 \\ \nu_1 & \nu_2 & \nu_3 & \nu_4 & \nu_5 & \nu_6 \\ & & & & & \end{matrix} \right| ,$$

that is to say, it is equal to

$$\Sigma|a_1b_2c_3d_4|\cdot|\lambda_1\mu_2\nu_3\rho_4|\,,$$

and consequently must vanish, because the first factor of every one of these products vanishes. The same is readily seen to be true of any other one of the fifteen determinants; in fact, the equivalents of the fifteen are

$$\begin{gathered}\Sigma|a_1b_2c_3d_4|\cdot|\lambda_1\mu_2\nu_3\rho_4|\\ \Sigma|a_1b_2c_3d_4|\cdot|\lambda_1\mu_2\nu_3\sigma_4|\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ \Sigma|a_1b_2c_3d_4|\cdot|\nu_1\rho_2\sigma_3\tau_4|\,,\end{gathered}$$

the difference between any two lying in the second factors only.

Conversely, if

$$0=\left\|\begin{matrix}\lambda_1a_1+\ldots+\lambda_6a_6 & \mu_1a_1+\ldots+\mu_6a_6 & \nu_1a_1+\ldots+\nu_6a_6 & \rho_1a_1+\ldots+\rho_6a_6 & \sigma_1a_1+\ldots+\sigma_6a_6 & \tau_1a_1+\ldots+\tau_6a_6\\ \lambda_1b_1+\ldots+\lambda_6b_6 & \mu_1b_1+\ldots+\mu_6b_6 & & & & \\ \lambda_1c_1+\ldots+\lambda_6c_6 & \mu_1c_1+\ldots+\mu_6c_6 & & & & \\ \lambda_1d_1+\ldots+\lambda_6d_6 & \mu_1d_1+\ldots+\mu_6d_6 & & & & \end{matrix}\right\|,$$

or, as we may write it, if

$$\left\|\begin{matrix}a_1 & a_2 & a_3 & a_4 & a_5 & a_6\\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6\\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6\\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6\end{matrix}\right\|\cdot|\lambda_1\mu_2\nu_3\rho_4\sigma_5\tau_6|=0\,,$$

it follows that

$$\left\|\begin{matrix}a_1 & a_2 & a_3 & a_4 & a_5 & a_6\\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6\\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6\\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6\end{matrix}\right\|=0,$$

provided that $|\lambda_1\mu_2\nu_3\rho_4\sigma_5\tau_6|=0$. For, as we have seen, the fifteen given equations are—

$$\left.\begin{gathered}\Sigma|a_1b_2c_3d_4|\cdot|\lambda_1\mu_2\nu_3\rho_4|=0,\\ \Sigma|a_1b_2c_3d_4|\cdot|\lambda_1\mu_2\nu_3\sigma_4|=0,\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ \Sigma|a_1b_2c_3d_4|\cdot|\nu_1\rho_2\sigma_3\tau_4|=0,\end{gathered}\right\}$$

where the summation-sign refers to the suffixes, and indicates that every possible set of four is to be taken out of 1, 2, 3, 4, 5, 6, and that the four indices of the second factor are always the same as those of the first; and if we solve for the fifteen unknowns $|a_1b_2c_3d_4|, |a_1b_2c_3d_5|, |a_1b_2c_3d_6|, \ldots, |a_3b_4c_5d_6|$ we must obtain the

result 0 for each of them, unless the determinant of their coefficients vanishes. Now, the determinant of their coefficients is the compound determinant whose elements are the minors of the 4th order formed from $|\lambda_1\mu_2\nu_3\rho_4\sigma_5\tau_6|$, and this by a well-known theorem is equal to the 10th power (*i.e.*, $C_{5,3}$) of $|\lambda_1\mu_2\nu_3\rho_4\sigma_5\tau_6|$. The theorem is thus established.

Cayley's last theorem closely resembles his second, being to the effect that if

$$\left\|\begin{matrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & c_3 & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{matrix}\right\| = 0 ,$$

then

$$\left\|\begin{matrix} a_1 & a_2 & \cdots\cdots & a_6 \\ \lambda_1 b_1 + \mu_1 c_1 + \nu_1 d_1 & \lambda_1 b_2 + \mu_1 c_2 + \nu_1 d_2 & \cdots\cdots & \lambda_1 b_6 + \mu_1 c_6 + \nu_1 d_6 \\ \lambda_2 b_1 + \mu_2 c_1 + \nu_2 d_1 & \lambda_2 b_2 + \mu_2 c_2 + \nu_2 d_2 & \cdots\cdots & \lambda_2 b_6 + \mu_2 c_6 + \nu_2 d_6 \\ \lambda_3 b_1 + \mu_3 c_1 + \nu_3 d_1 & \lambda_3 b_2 + \mu_3 c_2 + \nu_3 d_2 & \cdots\cdots & \lambda_3 b_6 + \mu_3 c_6 + \nu_3 d_6 \end{matrix}\right\| = 0 .$$

This amounts to saying that so far as multiplication by

$$\left|\begin{matrix} 1 & \cdot & \cdot & \cdot \\ \cdot & \lambda_1 & \lambda & \lambda \\ \cdot & \mu_1 & \mu_2 & \mu_3 \\ \cdot & \nu_1 & \nu_2 & \nu_3 \end{matrix}\right|$$

is concerned, the given rectangular array may be viewed as a single entity. The proof here is exactly similar to that of the analogous theorem, but is simpler; for the fifteen determinants of the new array are manifestly equal to

$$|a_1b_2c_3d_4|\cdot|\lambda_1\mu_2\nu_3| ,$$
$$|a_1b_2c_3d_5|\cdot|\lambda_1\mu_2\nu_3| ,$$
$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$
$$|a_3b_4c_5d_6|\cdot|\lambda_1\mu_2\nu_3| ,$$

that is to say, are merely multiples of the fifteen determinants of the original array, and must therefore vanish along with them.

The condition for the existence of the converse theorem is, evidently,

$$|\lambda_1\mu_2\nu_3| = 0 .$$

It is most important to notice that there is no reason for restricting the multiplier in the preceding theorem to the form

$$\begin{vmatrix} 1 & \cdot & \cdot & \cdot \\ \cdot & \lambda_1 & \lambda_2 & \lambda_3 \\ \cdot & \mu_1 & \mu_2 & \mu_3 \\ \cdot & \nu_1 & \nu_2 & \nu_3 \end{vmatrix} .$$

The method of proof which we have used shows that the multiplier might be any determinant whatever of the 4th order. This puts us in the position of being able to combine Cayley's two analogous theorems into one, as follows :—*If an array consisting of* r *rows and* n *columns* (r<n) *be such that all the determinants of the* r^{th} *order formed from it vanish, then the multiplication of the array row-wise by a determinant of the* n^{th} *order or column-wise by a determinant of the* r^{th} *order produces a similar array each of whose determinants of the* r^{th} *order will also vanish.*

Or, if

$$\left\Vert \begin{matrix} 11 & 12 & 13 \cdots 1n \\ 21 & 22 & 23 \cdots 2n \\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot\ \cdot \\ r1 & r2 & r3 \cdots rn \end{matrix} \right\Vert = 0 ,$$

then also

$$\left\Vert \begin{matrix} 11 & 12 & 13 \cdots 1n \\ 21 & 22 & 23 \cdots 2n \\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot\ \cdot \\ r1 & r2 & r3 \cdots rn \end{matrix} \right\Vert \cdot |\omega_{11}\omega_{22} \cdots \omega_{nn}| = 0 ,$$

and

$$\left\Vert \begin{matrix} 11 & 12 & 13 \cdots 1n \\ 21 & 22 & 23 \cdots 2n \\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot\ \cdot \\ r1 & r2 & r3 \cdots rn \end{matrix} \right\Vert \cdot |\omega_{11}\omega_{22} \cdots \omega_{rr}| = 0 .$$

And, conversely, if

$$\left\|\begin{matrix} 11 & 12 & 13 \cdots 1n \\ 21 & 22 & 23 \cdots 2n \\ \cdot & \cdot & \cdot \quad \cdot \quad \cdot \\ r1 & r2 & r3 \cdots rn \end{matrix}\right\| \cdot \Delta = 0 \,,$$

where Δ is a determinant of the n^{th} or r^{th} order, then

$$\left\|\begin{matrix} 11 & 12 & 13 \cdots 1n \\ 21 & 22 & 23 \cdots 2n \\ \cdot & \cdot & \cdot \quad \cdot \quad \cdot \\ r1 & r2 & r3 \cdots rn \end{matrix}\right\| = 0 \,,$$

provided that $\Delta \neq 0$.

Equation of the Glissette of the Two-term Oval $\frac{x^n}{a^n}+\frac{y^n}{b^n}=1$, and Cognate Curves. By the Hon. Lord M'Laren.

(Read January 19, 1891.)

The first step is to find an expression for the distances λ, μ, of the centre of the oval from the guides. These distances are to be found separately, beginning with λ.

For this purpose it is indifferent whether we consider the oval as moving in contact with the guides, or whether we consider the guides as variable tangents moving round the circumference of the oval. On the latter supposition, the extremity of λ is evidently the locus of the foot of the perpendicular on the tangent of the oval, whose equation is given in the title.

Let ξ, η be the cöordinates of this locus referred to the principal axes of the generating curve as reference lines. Then, by a known relation, the equation of the required locus is

$$(\xi^2+\eta^2)^{\frac{n}{n-1}}=(a\xi)^{\frac{n}{n-1}}+(b\eta)^{\frac{n}{n-1}} \quad . \quad . \quad . \quad (A).$$

The distance, λ, is the radius-vector corresponding to ξ and η:

$$\text{therefore } \xi=\lambda\cos\theta\,; \quad \eta=\lambda\sin\theta.$$

Substituting these values in (A) we have

$$\lambda^{\frac{2n}{n-1}}(\cos^2\theta+\sin^2\theta)^{\frac{n}{n-1}}=\lambda^{\frac{2n}{n-1}}=\lambda^{\frac{n}{n-1}}\{(a\cos\theta)^{\frac{n}{n-1}}+(b\sin\theta)^{\frac{n}{n-1}}\},$$

whence

$$\lambda^{\frac{n}{n-1}}=(a\cos\theta)^{\frac{n}{n-1}}+(b\sin\theta)^{\frac{n}{n-1}}\,; \quad . \quad . \quad . \quad . \quad (1)$$

Similarly,

$$\mu^{\frac{n}{n-1}}=(a\sin\theta)^{\frac{n}{n-1}}+(b\cos\theta)^{\frac{n}{n-1}}\,; \quad . \quad . \quad . \quad . \quad (2)$$

(by interchanging $\sin\theta$ and $\cos\theta$).

Next, let the cöordinates of the tracing-point (*i.e.*, its distances from the guides) be denoted by X, Y.

X is found from λ in the same way as in the case of the glissette of the ellipse, as given by Professor Tait (*Proc. Roy. Soc. Edin.*, vol. xvii. p. 2).

a and r (constants) are the polar cöordinates of the tracing-point,

reckoned from the centre of the generating curve as origin, and from its principal axis as reference-line, and we have, evidently,

$$X = \lambda \pm r \cdot \cos(\theta + \alpha)\,; \quad Y = \mu \pm r \cdot \sin(\theta + \alpha).$$

Finally, by substituting for λ and μ in (1) and (2), we get the simultaneous expressions for the glissette of the two-term oval, viz.:

$$X \mp r \cdot \cos(\theta + \alpha) = \{(a\cos\theta)^{\frac{n}{n-1}} + (b\sin\theta)^{\frac{n}{n-1}}\}^{\frac{n-1}{n}}\,; \quad . \quad \text{(I)}$$

$$Y \mp r \cdot \sin(\theta + \alpha) = \{(a\sin\theta)^{\frac{n}{n-1}} + (b\cos\theta)^{\frac{n}{n-1}}\}^{\frac{n-1}{n}}\,; \quad . \quad \text{(II)}$$

The equations of the glissette of the ellipse may be immediately formed from these by making the exponent $n = 2$. They are

$$X \mp r \cdot \cos(\theta + \alpha) = \{(a^2\cos^2\theta + b^2\sin^2\theta)\}^{\frac{1}{2}}\,;$$

$$Y \mp r \cdot \sin(\theta + \alpha) = \{(a^2\sin^2\theta + b^2\cos^2\theta)\}^{\frac{1}{2}}\,.$$

This method may be further generalised; because the equation (1) is the polar equation of the pedal of the generating curve, and (2) is the same equation for a corresponding point in the next quadrant of the pedal. Accordingly, whenever the pedal of a curve is known or can be found, the glissette of that curve can be obtained from the equation of the pedal in the manner above exemplified.

The equation of the pedal being represented by the generalised expression $\phi_n(R,\Theta,A) = 0$, then if the origin of cöordinates R,Θ, be taken as the tracing-point, the two equations of the glissette are given (in rectangular cöordinates, λ and μ) by writing in the first equation λ for R, leaving θ unchanged, and writing in the second equation μ for R, and $\left(\theta \pm \frac{\varpi}{2}\right)$ for θ;

$$\text{or } \phi_n(\lambda,\Theta,A) = 0\,; \quad \phi_n\left\{\mu_1\left(\theta \pm \frac{\varpi}{2}, A\right\} = 0.\right.$$

For any other tracing-point rigidly connected with the generating-curve, the first x-and-y equation of the glissette is derived from the polar equation of the pedal by substituting for R, the expression

$$x - r\cos(\theta + \alpha)\,,$$

and the second x-and-y equation is formed by substituting for R,

$$y - r\sin(\theta + \alpha)\,,$$

and also changing θ into $\left(\theta \pm \frac{\varpi}{2}\right)$. . . . . (III)

In these expressions, r is a line drawn from the tracing-point to the centre or origin of polar cöordinates of the pedal, and α is the inclination of that line to the axis of the generating curve, or reference line for its polar cöordinates.

If the angular coordinates of the generating curve and its pedal be of the form, $\cos \overline{m\theta}$, the glissette can be derived from the latter without expanding the quantity. Thus, if the generating curve be the negative-pedal of the parabola, or

$$R^{\frac{1}{3}} \cos\left(\frac{\theta}{3}\right) = a^{\frac{1}{3}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

the equation of the pedal, or common parabola, is

$$R \cos\left(\frac{\theta}{2}\right) = a^{\frac{1}{2}}, \quad \text{or} \quad R \cdot \cos^2\left(\frac{\theta}{2}\right) = a, \quad . \quad . \quad (2)$$

and the two equations of the glissette of (1) are by the above formula (III),

$$\left\{\begin{aligned} &(x - r \cdot \cos \overline{\theta + \alpha})\cos^2\left(\frac{\theta}{2}\right) = a\,; \\ &(y - r \cdot \sin \overline{\theta + \alpha})\cos^2\left(\frac{\theta - \varpi}{2}\right) = a\,. \end{aligned}\right\} \quad . \quad . \quad . \quad (3)$$

Again, if the generating curve be the parabola (2), the equation of the pedal is

$$R \cos \theta = a, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and the two equations of the glissette are, by (III),

$$\left\{\begin{aligned} &(x - r \cos \overline{\theta + \alpha})\cos \theta = a\,; \\ &(y - r \sin \overline{\theta + \alpha}) \cdot \cos\left(\theta - \frac{\varpi}{2}\right) = a, \text{ or } (y - r \cdot \sin \overline{\theta + \alpha}) \sin \theta = -a\,; \end{aligned}\right\} (5)$$

Note, that if the generating curve be a parabola of any degree, we must, in forming the 2nd equation of the glissette, substitute for $\cos\left(\frac{\theta}{n}\right)$ the value, $\cos\left(\frac{\theta}{n} - \frac{\varpi}{2}\right)$, or, in the case of the common parabola $(-\sin \theta)$. Hence a is negative in the second of the pair of equations (5).

The quantity θ may be eliminated from the equations (5) as follows :—

The equations of the glissette of the parabola, when expanded, are—

$$x \cos\theta - p\cos^2\theta + q\sin\theta\cos\theta - a = 0\,; \quad . \quad . \quad . \quad (a)$$
$$y \sin\theta - p\sin^2\theta - q\sin\theta\cos\theta + a = 0\,; \quad . \quad . \quad . \quad (b)$$

and by addition,

$$x\cos\theta + y\sin\theta - p = 0\,; \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

where $p = r\cos a$, and $q = r\sin a$.

Two new equations are to be formed (1st) by eliminating $\sin\theta$ between (a) and (c), and (2ndly) by squaring (c), viz.,

$$(py + qx)\cos^2\theta - (xy + pq)\cos\theta + ay = 0\,; \quad . \quad . \quad (1)$$
$$y^2\sin^2\theta = p^2 + x^2\cos^2\theta - 2px\cos\theta\,, \text{ or}$$
$$(x^2 + y^2)\cos^2\theta - 2px\cos\theta + (p^2 - y^2) = 0\,; \quad . \quad . \quad (2)$$

By (1st) eliminating $\cos^2\theta$ between (1) and (2), (2ndly) eliminating the terms independent of θ between the same equations, and (3rdly) eliminating $\cos\theta$ between the resulting equations, we find

$$\{(y^2 - p^2)(xy + pq) + 2apxy)\}\{2px(py + qx) - (x^2 + y^2)(xy + pq)\} =$$
$$\{(py + qx)(y^2 - p^2) + ay(x^2 + y^2)\}^2\,;$$

being a function of the *eighth* degree equated to a function of the *sixth*.

The elimination of the glissette of the ellipse may be performed in the same way, only in this case we have in (a), (b), and (c), instead of a and p, quantities containing x^2 and y^2. Hence for the ellipse (1) is of the 3rd degree, (2) is of the 4th degree, the two equations immediately derived from these are of the 5th and 6th degrees, and the final equation is of the 10th degree. Dr Muir has shown, in a paper just read, that the final equation is divisible by a quadratic factor, and is thus of the same degree as its limiting form, the glissette of the parabola.

Since the glissette of any curve may be found from the equation of the pedal (supposing the latter can be found), the glissette may be considered as belonging to a system of derivative curves which includes the pedal, the inverse, the reciprocal-polar, and (as shown by the writer in a previous paper) the caustic for parallel rays (*Proc. Roy. Soc. Edin.*, 1890, p. 280). In this system of derivative curves, the curves of each species are defined by a relation between the primitive

curve and the cöordinates of its tangents, normals, and radii, and the required equation is found by elimination between two equations, one of which is of the 1st degree. Other curves of the same system exist, and their equations may be found, *e.g.*, the locus of the intersection of normals, where a curve moves in contact with rectangular guides. Here the cöordinates, x and y, are the differences, $p_1 - \varpi_2$ and $p_2 - \varpi_1$; p_1, p_2 being the perpendiculars drawn from the pole of the curve to the tangent guides, and ϖ_1, ϖ_2 being the perpendiculars drawn from the pole to the normals.

The Influence of High Winds on the Barometer at the Ben Nevis Observatory. By Alexander Buchan, LL.D.

(Read March 2, 1891.)

The question of the effect of wind on the readings of the barometer was first examined by Sir Henry James in a paper read to the Society on March 15, 1852.* The observations were made during the succession of gales from the south-west which occurred in January and February of that year, at his house in Granton, with an aneroid barometer, laid horizontally in succession on the table of his room in the cottage, on the seat of the open summer-house, and on the surface of the ground close to the summer-house, all at the same level. The anemometer employed was of a very simple construction, being on the same principle as the instrument used for weighing letters, the weight or pressure being indicated by the compression of a spiral spring in a tube. A table of results is added, giving the depression of the barometer in decimals of an inch for the velocity of the wind from 14 to 40 miles per hour. At 14 miles the barometric depression was 0·010 inch, and increased gradually to a depression of 0·045 inch at 40 miles per hour. Unfortunately, the number of observations on which the depression for each wind-velocity has been deduced are not given, and the observations in the cottage and those at the open summer-house are combined into one result. It may be safely assumed that the results arrived at indicate too large barometric depressions for the different wind-velocities as barometers are usually observed, namely, in houses. The depression on the lee side of any obstruction in the wind such as a summer-house is greater than it is in the room of a dwelling-house. Further, a barometer laid on the ground during strong winds will, if the wind brush briskly over the key-hole of the instrument, indicate a less pressure than that of the air. Since, however, in such a position, the wind will only at a few points have access to the connecting opening between the aneroid and the free atmosphere, it may be assumed that the instrument

* *Transactions*, vol. xx. p. 377.

will, in the great majority of cases, show a higher reading than that of the free atmosphere. For these reasons, these barometric depressions are too large. Since 1852 meteorologists have taken no action on the results of Sir Henry James's inquiry in discussions on barometric readings and wind-velocities; and practically no advance has been made in this branch of meteorology. Various arrangements have been proposed, but none of them can be regarded as satisfactory, to arrive at the knowledge of the actual pressure of the free atmosphere during high winds. The difficulty consists in finding a perfectly unscreened position for the barometer, and securing at the same time that the wind, brushing past the small openings connecting the mercury of the cistern with the air outside, will not partially lower the pressure on the mercury in the cistern, and so render the instrument no longer indicative of the true pressure of the free atmosphere. The same remark applies to aneroids.

In carrying out, during the past five months, the instructions of the directors of the Ben Nevis Observatory to discuss the observations made at the High and Low Level Observatories, it quickly became apparent that the influence of high winds on the barometer was the first inquiry calling for serious attention. The depression of the barometer during high winds was plainly so serious as to render the examination of many questions all but a hopeless task, until some approximation was made to the values of these depressions for different wind velocities.

Now, since the horizontal distance of the High and Low Level Observatories is only about four miles, it follows that the two may virtually be treated as one as regards the geographical distribution of pressure. But the Observatory at the top of the mountain is peculiarly exposed to high winds, which are occasionally so violent that the observers must be roped together on going outside to make the observations; and it not unfrequently occurs that very strong winds prevail, while over the surrounding low country calms and light winds only prevail. On the other hand, the Low Level Observatory at Fort-William is in a sheltered position, and high winds are of comparatively rare occurrence. Thus, then, these two Observatories present the conditions which are essential to this inquiry, viz., one of the barometers is in a building exposed to

winds of all velocities up to at least 150 miles an hour, whereas the other is in a building where either calms or light winds only at the time prevail—so that this barometer may be regarded as recording the pressure of the free atmosphere. It was therefore resolved to institute a comparison between the sea-level pressures of these two barometers, employing only those cases when winds at the Fort-William Observatory were light.

The scale used on Ben Nevis for the observations of the force of the wind is a modification of Beaufort's scale, 0 to 12. Much attention has been given to ascertain the wind's rate in miles per hour, corresponding to each of the figures of Beaufort's scale. For this purpose, a modification of Robinson's anemometer was designed by Professor Chrystal for the Observatory; and during the times the instrument is not frozen up in a thick covering of ice, the comparisons have been made. These have been discussed by Mr Omond in a paper read to the Society. The comparison is given at the top of Table I.

The reductions of the barometric readings on the top of Ben Nevis to sea-level have been made by Table VIII. prepared for the purpose, as given in the volume of the *Transactions* recently published,* and the readings at Fort-William in the usual way. The differences of the two reduced readings were then entered in columns headed 0, 1, 2, 3, &c., and according to the wind force at the Ben Nevis Observatory at the time. Table I. gives the mean differences for each wind force for each wind; and the figures in the second half of the Table show the number of observations from which each mean difference has been calculated. The comparison for the six months was made from the hourly observations at both Observatories, from August 1890 to January 1891. But since this period gave too few observations for the higher wind velocities for good averages, the observations from January 1885 to July 1890 were utilised for the five hours of the day at which corresponding observations were made at Fort-William. Only the wind forces from 5 to 11 have been thus utilised, and the results have been incorporated with those for the six months, and entered at the foot of Table I. In all 4596 of the Ben Nevis observations have been reduced to sea-level for these comparisons.

* *Trans. Roy. Soc. Edin.*, vol. xxxiv. pp. 60–61.

TABLE I.—Showing (1) the Equivalent in miles per hour for the figures of Beaufort Scale; (2) the Depression of the Barometer, in inches, with increased Wind Velocity; and (3) the Number of Observations from which the Mean Results have been computed.

Beaufort's Wind Scale,	0	1	2	3	4	5	6	7	8	9	10	11	12
Equivalents in Miles per hour,	0	5	12	21	31	39	50	63	85	96	108	120	...
DIFFERENCES OF BAROMETER'S SEA-LEVEL READINGS.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	
1890—August,	– ·006	– ·002	– ·004	– ·003	– ·012	– ·024	– ·036	...	...	...	...	...	...
,, September,	– ·001	·000	·003	– ·001	– ·006	– ·013	– ·032	– ·047	– ·054	...	...	...	...
,, October,	– ·007	– ·006	– ·008	– ·011	– ·010	– ·047	– ·059	– ·096	...	...	...	...	...
,, November,	– ·009	– ·009	– ·007	– ·012	– ·014	– ·017	– ·028	– ·059	– ·096	– ·107	– ·143	– ·159	...
,, December,	·005	– ·001	– ·006	– ·011	– ·018	– ·035	– ·037	– ·047	– ·063	– ·085	– ·112	...	...
1891—January,	·002	– ·004	– ·010	– ·013	– ·012	– ·035	– ·054	– ·061	– ·062	– ·115	– ·094	...	..
Means,	– ·001	– ·004	– ·005	– ·010	– ·014	– ·026	– ·034	– ·052	– ·070	– ·103	– ·127	– ·159	...
NUMBER OF OBSERVATIONS AVAILABLE IN CALCULATING THE ABOVE.													
1890—August,	341	195	124	37	22	11	12	...	...	...	...	...	...
,, September,	67	143	213	139	36	38	28	33	14	...	...	...	...
,, October,	50	135	242	208	81	14	1	1	...	...	...	...	...
,, November,	46	148	164	167	79	42	26	20	10	14	7	4	..
,, December,	45	97	140	183	163	78	21	11	2	4	1	...	..
1891—January,	65	198	238	158	42	10	6	4	3	1	3	...	...
Sums,	614	916	1121	892	423	193	94	69	29	19	11	4	...
*Depression of Barometers, Means,	– ·001	– ·004	– ·005	– ·010	– ·014	– ·026	– ·035	– ·050	– ·070	– ·104	– ·122	– ·150	...
*Number of Observations,	614	916	1121	892	423	221	144	123	64	42	20	16	...

* These last Means and Sums are inclusive of all cases of Wind Force from 5 to 11 recorded in the years January 1885 to July 1890.

The following summarises the results, showing the depression of the barometer with each wind velocity:—

Miles per hour.	Baro. Depression. inch.	Miles per hour.	Baro. Depression. inch.
0	−0·001	50	−0·035
5	−0·004	63	−0·050
12	−0·005	83	−0·070
21	−0·010	96	−0·104
31	−0·014	108	−0·122
39	−0·026	120	−0·150

Thus in calm weather, the two reduced barometers are practically the same, but with every increase of wind the depression of the barometer steadily augments. It is not till a velocity of more than 20 miles an hour is attained that the depression amounts to one hundredth of an inch. At 63 miles an hour, it is 0·050 inch; at 96 miles, 0·104 inch; and at 120 miles, 0·150 inch. The amount of the depression of the barometer is thus practically proportional to the velocity of the wind, from zero to a velocity of 120 miles per hour.

This depression of the barometer is no doubt occasioned by the wind drawing out the air from the room where the barometer is hung, as it rushes past the observatory, thus producing a partial vacuum and consequently a lower pressure. If a window or door is opened on the side of the room exposed to the wind, the readings of the barometer are thereby raised; whereas on the lee side of buildings, in rooms connected therewith, and in rooms with chimneys, the barometric readings are lowered. Now, as the barometer of the Ben Nevis Observatory is hung in a room, with the usual chimney, door, and windows, these results may be regarded as applicable to the readings of barometers generally, since they are in almost every case suspended in situations similar to that of the Ben Nevis barometer.

In a paper on the Mean Atmospheric Pressure of the British Islands, published by the Scottish Meterological Society ten years ago,* monthly and annual isobars are given for every two-hundredths of an inch of pressure. These isobars show a lower pressure over those parts of the country where the prevailing winds are stronger than elsewhere. It may now be regarded as probable that the curved courses taken by the isobars do not indicate any

* *Journal Scot. Meteorol. Soc.*, new series, vol. vi. p. 4–40.

real lowering of atmospheric pressure in these districts, but are only an increased depression of the barometer brought about by the stronger winds which prevail in those parts of the country.

In forecasting weather it will be necessary to keep this effect of high winds on the barometer constantly in mind, with the view of arriving at a better approximation to the real geographical distribution of pressure at the time the forecasts are being framed.

In working out the question of the barometric gradient from actual observations, particularly the relations of the higher gradients to the wind velocities, the results hitherto arrived at cannot be said to be satisfactory. The reason is that, while the wind velocities were known with tolerable accuracy, the pressure of the free atmosphere could not be dealt with, because the observations did not record it; what the observatories recorded was only the barometric readings, not reduced proportionally to the force of the wind at each observatory. For such discussions to be satisfactory, the amount of the depression of the barometer, owing to the force of the wind prevailing at the time, should be approximated to and allowed for.

Table II., showing the mean diurnal variation of the differences between the two reduced barometers for the six months has been prepared in this way: The differences for each hour of the day were corrected by adding, in each case, the corrections indicated in Table I., according to the wind force at the time, from which the monthly means were calculated. The six months' means show that from 7 P.M. to 9 A.M., the reduced High Level Barometer reads the higher, and from 10 A.M. to 6 P.M. that it reads the lower.

In these reductions the mean temperature of the stratum of atmosphere from the bottom to the top of the mountain has been assumed to be the same as the mean at the two observatories. If it be supposed that the diurnal variations for the six months in Table II. are simply an expression of the degree to which the mean temperature of the two observatories falls short of, or exceeds, the mean of the whole intervening stratum, it follows that during the warmer hours of the day the temperature of the whole intervening stratum is about 0°·8 lower, and during the colder hours of the night 0°·8 higher than the mean of the two observatories.

The variations of differences are of course much larger and more uniform in their distribution during the hours of the day. It will

be observed that the means for August and September differ considerably from each other. The results point to two marked peculiarities in the differences of the reduced barometers in wet, cyclonic weather, as shown by the August curve; and in dry, anti-cyclonic weather, as in the September curve. During the times of abnormally high temperature and great dryness, which are so characteristic of anti-cyclonic weather, the reduced barometer at the top reads higher than at Fort-William; and, on the other hand, during advancing cyclones, when the atmosphere is highly charged with vapour, the reduced barometer at the top reads lower.

TABLE II.—Showing the Mean Diurnal Variation of the Differences between the Reduced Barometers of the two Observatories for the Six Months ending January 1891. The minus sign indicates that the mean of the reduced High Level Barometer was the lower of the two; no sign that it was the higher.

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	6 Months
	inch.	inch.	inch.	inch.	inch.	inch.	inch.
1 A.M.	·010	·016	·002	·000	·002	– ·005	·004
2 ,,	·007	·017	·000	– ·002	·005	– ·005	·004
3 ,,	·007	·018	·001	·000	·004	– ·006	·004
4 ,,	·007	·016	– ·001	·003	·001	– ·007	·003
5 ,,	·006	·012	·002	·001	·000	– ·001	·003
6 ,,	·002	·012	·002	– ·002	– ·001	·000	·002
7 ,,	·001	·012	·003	·002	·001	·001	·003
8 ,,	– ·006	·007	– ·001	·002	– ·001	·003	·001
9 ,,	– ·008	·003	– ·002	·001	·003	·004	·000
10 ,,	– ·011	·001	– ·005	– ·002	·002	– ·002	– ·003
11 ,,	– ·010	·001	– ·006	– ·004	– ·002	– ·001	– ·004
Noon.	– ·012	·003	– ·007	– ·005	– ·006	– ·001	– ·005
1 P.M.	– ·009	·007	– ·007	– ·009	– ·006	– ·001	– ·004
2 ,,	– ·009	·001	– ·007	– ·007	– ·006	– ·006	– ·006
3 ,,	– ·009	·001	– ·007	– ·006	– ·005	– ·004	– ·005
4 ,,	– ·007	·002	– ·009	– ·007	– ·004	– ·002	– ·004
5 ,,	– ·005	·007	– ·002	– ·007	– ·003	·006	– ·001
6 ,,	– ·004	·007	– ·003	– ·009	– ·001	·004	– ·001
7 ,,	·002	·015	·002	– ·005	·000	·004	·003
8 ,,	·003	·015	– ·002	– ·006	·002	– ·004	·001
9 ,,	·007	·021	·002	– ·004	·004	– ·002	·005
10 ,,	·007	·017	·003	– ·003	·001	– ·004	·004
11 ,,	·009	·020	·002	·003	·003	– ·003	·006
Midnight	·008	·018	·000	·001	– ·001	– ·005	·004

Electrolytic Synthesis of Dibasic Acids. Alkyl Derivatives of Succinic Acid. By Professor Crum Brown and Dr James Walker.

(Read April 6, 1891.)

(*Abstract.*)

In our previous communications to the Society (see *Trans.* xxxvi. 211) we described the behaviour of the ethyl potassium salts of normal dibasic acids on electrolysis. These we found always to yield the diethyl esters of normal acids of the same series. We have now extended our investigation to acids with side chains, and in this paper give an account of the electrolysis of ethylpotassium methylmalonate and ethylpotassium ethylmalonate.

The esters formed according to the general equation, 2EtO(CO).R″.(CO)O– = EtO(CO).R″.R″.(CO).OEt + $2CO_2$, are evidently always symmetrical, so that from methylmalonic acid we should expect to obtain symmetrical dimethylsuccinic acid:—2EtO(CO).CH(CH_3).(CO)O– = EtO(CO).CH(CH_3).CH(CH_3).(CO)OEt + $2CO_2$. This dimethylsuccinic acid contains two similarly situated asymmetric carbon atoms, and is thus, like tartaric acid, capable of existence in four isomeric forms—two optically active, and two optically inactive, one of these latter (corresponding to racemic acid) being a compound or mixture in equal proportions of the two opposite optically active acids. As the optically active forms are produced in equal proportions by any purely chemical process from inactive materials, we were justified in expecting to obtain by electrolysis a mixture of the esters of the two inactive symmetrical dimethylsuccinic acids.

The synthesis was conducted in precisely the same manner as in our previous experiments. 150 grams of ethylpotassium methylmalonate yielded about 60 grams of an ethereal product, which, on distillation, gave a fraction of 30 grams, boiling between 194° C. and 206° C. This portion was saponified with boiling alcoholic potash, and the potassium salt thus formed converted into the

acid, which was then extracted with ether. The crude acid was freed from a small quantity of an oily substance by drying on porous tile, and then subjected to systematic fractional crystallisation from water. We succeeded in separating and purifying two acids—one, the less soluble, having the melting-point 193° C., the other melting at 120°–121° C. The acids on analysis proved to have the same composition, both corresponding to the formula $C_6H_{10}O_4$.

I. ·1166 gr. more soluble acid gave ·2100 gr. CO_2
and ·0737 gr. H_2O

II. ·1350 gr. less soluble acid gave ·2432 gr. CO_2
and ·0855 gr. H_2O

	Found. I.	Found. II.	Calculated for $C_6H_{10}O_4$
C	49·12	49·13	49·31
H	7·02	7·04	6·87

The acid melting at 193° would thus seem to be identical with the para-*s*-dimethylsuccinic acid of Bischoff (melting-point 194°); and that melting at 120°–121° with his anti-*s*-dimethylsuccinic acid (melting-point 120°). For further confirmation we measured the electrolytic conductivity of solutions of the acids, and found the following dissociation-constants :—

Para-acid, K = ·0208 (K = ·0205, Bethmann).
Anti-acid, K = ·0138 (K = ·0122, Bischoff and Walden).

In a similar manner we performed the electrolysis of ethyl potassium ethylmalonate, and from 150 grams of the salt obtained 63 grams of an ethereal liquid. The portion of this boiling above 200°, was saponified, the potassium salt acidified, and the crude acid extracted with ether and purified as in the preceding case. Besides water as a means of fractional crystallisation, we found benzene a useful solvent for effecting the separation of the isomeric acids. As before, we obtained in the pure state two acids, one melting at 192° C. with decomposition, the other at 130° C. Analysis gave the following numbers :—

I. ·1252 gr. acid, melting-point 192° C., gave ·2530 gr. CO_2
and ·0915 gr. H_2O

II. ·1224 gr. acid, melting-point 130° C., gave ·2465 gr. CO_2
and ·0894 gr. H_2O

	Found. I.	Found. II.	Calculated for $C_8H_{14}O_4$
C	55·11	54·93	55·17
H	8·12	8·12	8·11

The acids have thus the composition of diethylsuccinic acid, and from their mode of formation are symmetrical. Two symmetrical diethylsuccinic acids were prepared by Bischoff and Hjelt, which are evidently identical with ours, viz., para-*s*-diethylsuccinic acids, melting-point 192°, with decomposition, and anti-*s*-diethylsuccinic acid, melting-point 129°. We found the following values of the dissociation-constants of the two acids:—

Para-acid, K = ·0237 (K = ·0245, Bischoff and Walden).
Anti-acid, K = ·0347 (K = ·0343 " ").

Proposed Extension of the Powers of Quaternion Differentiation.

By **Alexander M'Aulay,** Ormond College, Melbourne. *Communicated* by Professor TAIT.

(Read December 15, 1890.)

It will, I think, be acknowledged that Quaternions, while providing for the physicist a machinery much more natural and graceful than the Cartesian, for all conceptions strictly geometrical, do not at present afford equal facilities for the consideration of questions involving differentiation. It is true that there is one well-known symbol of differentiation of great utility, which enables Quaternions to deal in a suitable manner with many such questions; but there are left whole classes of differentiations in which the symbol is of no avail.

This has led me to the consideration of other symbols of differentiation, and to a slight generalisation of the powers of the symbol already mentioned. I had thought it necessary only to define the extensions here referred to, and proceed to apply them. But Professor Tait, while kindly procuring me this opportunity of bringing forward my views, has given me fair warning that the repugnance of physicists to some of my notation may prove an insuperable obstacle to their paying any attention to investigations conducted in that notation. This personal reference will explain why, in the present short paper, an apology for, and explanation of, the methods are entered into, much more detailed than could otherwise be considered advisable or even justifiable.

In what follows, after an explanation of the proposed changes of, and additions to, quaternion differential notation, a brief account in the abstract is given of the reasons for and against what can be called innovation; and the rest of the paper is devoted to some examples of the application to the theories of elasticity and electrostatics. I may here remark that, in a short paper like the present, it is impossible to do full justice to the views enunciated, because for this purpose it would be necessary to go over a large part of the ground covered by mathematical physics; but if the slight variations from previous custom indicated below do not meet with

that studied discountenance from all authorities in the matter, which I have been assured they must, I could give in a future paper some few applications of the methods which would probably prove interesting to physicists, and which cannot be treated readily, if at all, by methods other than those in question.

As is well known, Hamilton's symbol ∇ may be defined by the equation

$$\nabla = i\frac{d}{dx} + j\frac{d}{dy} + k\frac{d}{dz}$$

where i, j, k, x, y, z have the usual meanings. Hamilton himself did not examine the utility of ∇. This explains, most likely, why he did not state more exactly how to consider to what symbols the differentiations implied should refer. In the simplest applications of ∇ these differentiations will refer to that symbol, and only to it, which immediately follows the operator. Very little practice in the application of ∇ to physical questions serves to show that, if we are to be bound by this rule, at least seven-eighths of the potential utility of ∇ must be sacrificed. Professor Tait has recognised this in the 3rd edition of his *Quaternions*, where he freely separates the ∇ from the symbol or symbols it affects; and, according to a well-known custom, indicates the connection between the operator and the symbols affected by attaching the same suffix to both. This I had already done in a paper to be referred to immediately. We seem then to be led by a natural process to the following statement:—

The operator ∇ and its operand or operands may have any relative positions in a term which are convenient, the connection between them being indicated in the usual way by suffixes.

For the propriety of this view, I now wish to contend, although at the time of writing the 3rd ed. of *Quaternions* Professor Tait was not prepared to endorse it in full. Notwithstanding that it is immaterial how great, in a term, be the separation of a ∇ from the symbol affected, so long as the ∇ is on the *left* of the symbol, he* emphatically—observe his italics—lays down the law, that the ∇ must not be removed to the *right* of the symbol, even the immediate

* With regard to the use of ∇ Professor Tait (*Quaternions*, 3rd ed., § 149) says :—"The precautions necessary in such matters are twofold—(*a*) *The operator must never be placed after the operand; (b) its commutative or non-commutative character must be carefully kept in view.*"

right. Is it not akin to inconsistency to say in effect—"It is justifiable to violate, for convenience, the custom of writing an operator to the immediate left of the symbol affected, and to indicate the connection by some other method, but the justification only covers a *limited* violation of the custom. It matters not that the new method of indication will equally well serve *whatever* be the relative positions in a term of the operator and the symbol affected—we will strictly adhere to one part of the restriction hitherto imposed upon this relativity of position, though freeing ourselves from the other."

It may be—has been—urged that to place a ∇ to the right of the symbol affected is as criminally ridiculous as to write $X\frac{d}{dx}$ for $\frac{dX}{dx}$. It may be equally well urged that the removal of ∇ to the left from its primitive position is on a par with writing $\frac{d}{dx}XY$ for $X\frac{dY}{dx}$.

It must be conceded that both of these violations of custom are objectionable, and cannot be justified, unless some convenience accrues greater than the counterbalancing inconvenience of having to show by some method, other than that of juxtaposition, the connection between the operator and the symbol affected. Whether such convenience does exist must be left undecided till we come to the applications. What I want to point out here is, that it is extremely inconvenient, and there is absolutely no ground whatever for not utilising this new method of indication in all cases where it is applicable.

To take an instance. In considering Maxwell's electrostatic theory below, we are led to consider the very simple stress, whose corresponding linear vector function ϕ is given by the equation

$$\phi\omega = V\mathfrak{D}\omega\mathfrak{E},$$

where $\mathfrak{D}$ and $\mathfrak{E}$ are the electric displacement and electro-motive force respectively.* The force per unit volume due to this is

$$\frac{d\phi i}{dx} + \frac{d\phi j}{dy} + \frac{d\phi k}{dz} = \frac{dV\mathfrak{D}i\mathfrak{E}}{dx} + \frac{dV\mathfrak{D}j\mathfrak{E}}{dy} + \frac{dV\mathfrak{D}k\mathfrak{E}}{dz}.$$

* Maxwell's *Elect. and Mag.*, 2nd ed., § 68.

Now, what possible objection can there be to writing this last equation in the form

$$\phi_1 \nabla_1 = V\mathfrak{D}_1 \nabla_1 \mathfrak{E}_1 \; . \; . \; . \; . \; . \; . \; . \; . \quad (1).$$

On the left of this equation the ∇, as indicated by the suffixes, refers to the symbol immediately preceding it. On the right it refers to both the symbol immediately preceding and also to that immediately following. Certainly the expression on the right can be written

$$V\mathfrak{D}\nabla\mathfrak{E} + V\mathfrak{E}\nabla\mathfrak{D}\,;$$

but in this shape we at once lose the connection of form between the vector in question and the corresponding linear vector function $V\mathfrak{D}(\ )\mathfrak{E}$.

Professor Tait suggests in his treatise how such vectors as $\phi_1 \nabla_1$ above may be treated. He shows how we may prove properties of the vector, and even suggests a method of writing down the vector. Adopting that suggestion, we should have, instead of equation (1) above

$$-S\nabla\Delta.\phi\rho = -S\nabla\Delta.V\mathfrak{D}\rho\mathfrak{E}.^*$$

To explain my notation I will quote from a paper † on this subject, written in 1884:—

"If ϕ be any *linear quaternion function*, ϕ itself being a function of the position of a point

$$\phi\Delta = \frac{d\phi i}{dx} + \frac{d\phi j}{dy} + \frac{d\phi k}{dz}\,.$$

It is necessary, as will be seen below, that this Δ should be distinguished from ∇.

Whenever numerical suffixes occur in this paper it will be to

* Tait's *Quaternions*, 3rd ed., § 508. The following words of Professor Tait seem to me to form a powerful argument in favour of my *natural* notation :—" *The highest art is the absence of artifice.* . . . . The difficulties of Physics are sufficiently great in themselves to tax the highest resources of the human intellect; to mix them up with avoidable mathematical difficulties is unreason little short of crime. . . . . In Quaternions, a subject uniquely adapted to Euclidian space, this entire freedom from artifice and its inevitable complications is the chief feature. . . . . What is required for Physics is, that we should be enabled at every step to feel instinctively what we are doing. Till we have banished artifice we are not entitled to hope for full success in such an undertaking" (Tait, "On the Importance of Quaternions in Physics," *Phil. Mag.*, 5th series, vol. xxix. pp. 84–97).

† *Mess. of Math.*, vol. xiv. p. 26. I have substituted in the present paper Δ for the ∇' of the original paper.

show to what quantities the operator ∇ refers, both the ∇ and the quantities having, for this purpose, the same suffix. Thus below,

$$* \, \mathrm{V}\nabla_1\sigma_2\mathrm{S}\sigma_1\nabla_2 = \mathrm{V}i\frac{d\sigma}{dx}\mathrm{S}\frac{d\sigma}{dx}i + \mathrm{V}j\frac{d\sigma}{dz}\mathrm{S}\frac{d\sigma}{dy}k + \ldots$$

One advantage of this notation is, that the ∇_1's, ∇_2's, &c., as well as the σ_1's, σ_2's, &c., can be treated as mere vectors."

It is this last statement which points to the most powerful argument for not restricting the position of the ∇'s in a term in any way. Let them have all the freedom of vectors, and they will obey all the laws thereof. As soon as we allow this freedom, but not till then, can we draw upon the large storehouse of already accumulated knowledge of vectors.†

It will be observed that in the above definitions there is no absolute need for introducing the symbol Δ. It is, however, as in many cases of duplicate notation, extremely convenient. Its differentiations refer to *all* the symbols in the term in which it occurs. Thus, for instance, the above equation (1) can be written

$$\phi\Delta = \mathrm{V}\mathfrak{D}\Delta\mathfrak{E},$$

which still more clearly shows the connection between the stress $\mathrm{V}\mathfrak{D}(\ )\mathfrak{E}$ and the resulting force per unit volume $\mathrm{V}\mathfrak{D}\Delta\mathfrak{E}$.

With these definitions, Professor Tait's well-known theorems in integration can be thrown into a rather more general form.‡ If ϕ be any linear quaternion function of a quaternion, then with Professor Tait's (*Quaternions*, 3rd ed., § 482) notation for integration—

* According to Professor Tait this *must* be written in some such form as the following:—$\mathrm{V}\nabla_1(\mathrm{S}\nabla_2\sigma_1)\sigma_2$ or $-\mathrm{S}\nabla_3\nabla_1.\mathrm{V}\nabla_2\sigma_1\mathrm{S}\rho_3\sigma_2$ or $-\mathrm{S}\nabla_3\nabla_1\mathrm{S}\nabla_2\sigma_1.\mathrm{V}\rho_3\sigma_2$. Even if the first of these is chosen, it may be pertinently asked why symbols which will, in the nature of things, obey all the laws of vectors, should be restricted in a purely arbitrary manner in obeying those laws. Why should we not be allowed to ring all the possible changes on the form of $\mathrm{V}\nabla_1\sigma_2\mathrm{S}\sigma_1\nabla_2$ as on that of $\mathrm{V}\alpha\beta\mathrm{S}\gamma\delta$, and reap the corresponding advantages?

† In the *Trans. Roy. Soc. Edin.*, xxvii. p. 251 (1874), Dr Plarr suggests the notation $\triangleleft r = i\frac{dr}{dx} + \ldots$, $\triangleright r = \frac{dr}{dx}i + \ldots$ where r is any quaternion. He suggests no notation for $\frac{d\phi\bar{i}}{dx} + \ldots$ where ϕ is a general linear quaternion function. His symbols $\triangleleft$ and $\triangleright$ do not obey the laws of vectors, the first only because it is not allowed the freedom of a vector.

‡ The proof is given in the paper already quoted from.

$$\int\phi(d\rho)=\iint\phi(\mathrm{V}\,\mathrm{U}\nu\,\Delta)ds \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$
$$\iint\phi\mathrm{U}\nu ds=\iiint\phi\,\Delta\,d\varsigma \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

The last equation shows at once, as pointed out in the paper already referred to, that the stress ϕ (when ϕ has the particular form of a *vector* function of a vector) causes a force per unit volume $\phi\,\Delta$.

Before considering the properties and applications of ∇ in this extended form, I will now introduce all the innovations that I propose.

A large class of differentiations can be included under a symbol somewhat analogous to ∇. Suppose we have a linear vector function, ϕ, of a vector depending on the nine scalars, a, b, c, a', b', c', a'', b'', c'', by means of the equations—

$$\begin{aligned}\phi i &= ai + bj + ck\\ \phi j &= a'i + b'j + c'k\\ \phi k &= a''i + b''j + c''k\end{aligned}$$

Then a, b, c, a', &c., can be called the coordinates of ϕ. Again, P, Q, R, L, M, N may be called the coordinates of the self-conjugate linear vector function, ϖ, of a vector, if

$$\begin{aligned}\varpi i &= \mathrm{P}i + \mathrm{N}j + \mathrm{M}k\\ \varpi j &= \mathrm{N}i + \mathrm{Q}j + \mathrm{L}k\\ \varpi k &= \mathrm{M}i + \mathrm{L}j + \mathrm{R}k\,.\end{aligned}$$

Now, just as, if u, v, w are the coordinates of an independent vector σ, ${}_\sigma\nabla$ may be defined as a symbolic vector, whose coordinates are $\frac{d}{du}$, $\frac{d}{dv}$, $\frac{d}{dw}$; so if a, b, c, a', b', c', a'', b'', c'' be the coordinates of an independent linear vector function, ϕ, of a vector, ${}_\phi\mathfrak{a}$ may be* defined as a symbolic linear vector function, whose coordinates are—

$$\frac{d}{da},\quad \frac{d}{db},\quad \frac{d}{dc},\quad \frac{d}{da'},\quad \frac{d}{db'},\quad \frac{d}{dc'},\quad \frac{d}{da''},\quad \frac{d}{db''},\quad \frac{d}{dc''}.$$

If ϖ be an independent *self-conjugate* linear vector function of a

* I use the inverted D to suggest the analogy to Hamilton's inverted Δ. It is advisable to write ${}_\phi\mathfrak{a}$, ${}_\sigma\nabla$, &c., instead of $\mathfrak{a}_\phi$, ∇_σ, &c., as the numerical suffixes must be much more frequently introduced than the symbols ϕ or σ, which may be very frequently understood, and it is not advisable that both the literal and numerical suffixes should be on the same side of the $\mathfrak{a}$ or ∇.

vector, whose coordinates are P, Q, R, L, M, N, $_{\varpi}\mathrm{a}$ is defined as meaning the symbolic self-conjugate linear vector function of a vector, whose coordinates are—

$$\frac{d}{d\mathrm{P}}, \quad \frac{d}{d\mathrm{Q}}, \quad \frac{d}{d\mathrm{R}}, \quad \frac{1}{2}\frac{d}{d\mathrm{L}}, \quad \frac{1}{2}\frac{d}{d\mathrm{M}}, \quad \frac{1}{2}\frac{d}{d\mathrm{N}}.$$

This twofold meaning for a leads to no confusion, and is convenient, as all the formulæ which are true of one a are true of the other also. To a may be attached a system of suffixes for the same objects and with the same meanings, as in the case of ∇.

It is convenient, though not absolutely necessary, to introduce one other symbol. Suppose $\mathrm{Q}(\alpha,\beta)$ is a function of two vectors, linear *in each.* Then we have

$$\mathrm{Q}(\nabla_1,\rho_1) = \mathrm{Q}(i,i) + \mathrm{Q}(j,j) + \mathrm{Q}(k,k),$$

so that ∇_1 and ρ_1 may be interchanged. This particular use of ∇ is so frequent that it is advisable to use a symbol which will call attention to the symmetry. I therefore define ζ by the equation

$$\mathrm{Q}(\nabla_1,\rho_1) = \mathrm{Q}(\zeta_1,\zeta_1).$$

Similarly, if $\mathrm{Q}(\alpha,\beta,\gamma,\delta)$ be a function of four vectors, $\alpha,\beta,\gamma,\delta$, linear in each, we may put

$$\mathrm{Q}(\nabla_1,\rho_1,\nabla_2,\rho_2) = \mathrm{Q}(\zeta_1,\zeta_1,\zeta_2,\zeta_2),$$

and so to any number of pairs of ζ's. Of course if there be only one pair the suffix may be dropped entirely.

I now state a number of theorems in pure mathematics which will be useful, for brevity leaving them unproved.

If ϕ be any linear vector function of a vector, and ϕ' be its conjugate,

$$\phi'\omega = -\zeta \mathrm{S}\omega\phi\zeta \quad \ldots \ldots \ldots \quad (4),$$
$$(\phi - \phi')\omega = \mathrm{VV}\zeta\phi\zeta.\omega \quad \ldots \ldots \ldots \quad (5).$$

If $\mathrm{Q}(\alpha,\beta)$ be any quaternion function of two vectors, α and β, which is linear in each,

$$\mathrm{Q}(\zeta,\phi\zeta) = \mathrm{Q}(\phi'\zeta,\zeta) \quad \ldots \ldots \ldots \quad (6).$$

To apply this in practice, it is convenient to remember it in words:— *In any term in which ζ and $\phi\zeta$ occur, we may, without altering the value of that term, substitute for them $\phi'\zeta$ and ζ respectively.* (It is

not necessary to say that the term is linear in each of the symbols ζ and $\phi\zeta$, for from the definition of ζ it must be so.) If

$$\left.\begin{array}{l}\phi\omega = -\Sigma\beta S\omega\alpha \\ Q(\zeta,\phi\zeta) = \Sigma Q(\alpha,\beta)\end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7).$$

If Q *be symmetrical in its constituents*, and if

$$\left.\begin{array}{l}\varpi\omega = -\tfrac{1}{2}\Sigma(\beta S\omega\alpha + \alpha S\omega\beta) \\ Q(\zeta,\varpi\zeta) = \Sigma Q(\alpha,\beta)\end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (8).$$

If m have the usual* meaning with reference to the linear vector function ϕ

$$6m = S\zeta_1\zeta_2\zeta_3 S\phi\zeta_1\phi\zeta_2\phi\zeta_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

$$\phi^{-1}\omega = -\frac{3V\zeta_1\zeta_2 S\omega\phi\zeta_1\phi\zeta_2}{S\zeta_1\zeta_2\zeta_3 S\phi\zeta_1\phi\zeta_2\phi\zeta_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10).$$

From these we deduce that if

$$\left.\begin{array}{l}\phi\omega \;\; = -S\omega\nabla.\sigma \\[2ex] \phi^{-1}\omega = -\dfrac{3V\nabla_1\nabla_2 S\omega\sigma_1\sigma_2}{S\nabla_1\nabla_2\nabla_3 S\sigma_1\sigma_2\sigma_3} \\[2ex] \phi'^{-1}\omega = -\dfrac{3V\sigma_1\sigma_2 S\omega\nabla_1\nabla_2}{S\nabla_1\nabla_2\nabla_3 S\sigma_1\sigma_2\sigma_3}\end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (11).$$

If ϕ and ψ, two linear vector functions of a vector, be connected by the equation

$$S\phi\zeta\chi\zeta = S\psi\zeta\chi\zeta\,,$$

where χ is a *perfectly arbitrary* linear vector function of a vector,† it follows that

$$\phi \equiv \psi\,,$$

or, again, if χ be self-conjugate but otherwise perfectly arbitrary and the above equation hold, it follows that

$$\bar{\phi} \equiv \bar{\psi}$$

where

$$2\bar{\phi} = \phi + \phi'$$

and similarly for $\bar{\psi}$, *i.e.*, $\bar{\phi}$, $\bar{\psi}$ are the pure parts of ϕ and ψ.

* Tait's *Quaternions*, 3rd ed., §§ 158 *et seq.*

† This frequently-recurring and cumbrous phrase is very annoying. Might I suggest the term *Hamiltonian.* Thus, in the present case, we should say—"If ϕ and ψ be two Hamiltonians connected by the equation $S\phi\zeta\chi\zeta = S\psi\zeta\chi\zeta$ where χ is a perfectly arbitrary Hamiltonian," &c.

If Q be any function of an independent variable vector σ, we already know (Tait's *Quaternions*, 3rd ed., § 480) that

$$dQ = -Sd\sigma_{\sigma}\nabla . Q \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12).$$

A similar theorem in $\mho$ holds. If Q be any function of an independent variable linear vector function of a vector ϕ (whether general or self-conjugate)

$$dQ = -Q_1 Sd\phi\zeta_{\phi}\mho_1\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13).$$

From this it is not hard to show that $\mho$ is an invariant. That is, it is a symbol, independent in meaning of the three mutually perpendicular unit vectors, i, j, k, used in defining it.

I now proceed to a few examples of the use, in the subject of *Elasticity*, of the symbols introduced.

Assuming uniformity of temperature throughout, let us investigate the general equations connected with the state of an elastic body. The two usual assumptions will not be made (1) that the strain is small, and (2) that there is no molecular couple. Let $d\varsigma$ be the volume of an element in some standard state—say the initial state. We assume that the pot. en. of any finite volume of the body is of the form $\iiint wd\varsigma$, where w depends only on the state as to strain of the body at the point. (Notice that it is not here assumed, as I believe is invariably done, that w depends only on the *coordinates* of pure strain at the point. It may, *e.g.*, so far as we know at present, involve also the space-derivatives of those coordinates. We do, however, assume that it is not a function of the state of the body at a point that is at a finite distance from the point under consideration.)

Our first object will be to get, not the equations of motion, but the equations connecting stress and strain. As will be seen, these two problems are not necessarily identical. The plan adopted is to assume the body to be strained in the most general manner. Then impose the most general small additional strain, and use the principle that for any finite portion of the body

$$\begin{aligned}\iiint \delta w d\varsigma = &\text{(work done by stresses on boundary of portion)}\\ &-\text{(work done by stresses throughout volume of portion)} \quad (14)\end{aligned}$$

Let ρ be the coordinate vector of the element $d\varsigma$ in its standard

position, ρ' the coordinate in the strained position, and $\rho'+\delta\rho'$ in the additionally strained position. Let ∇ have the usual meaning with regard to ρ and ∇', the same meaning with regard to ρ' (so that in the notation of p. 103 above, $\nabla' = {}^{\rho'}\nabla$).

Let at a given point ω be the vector area of an elementary interface *in its strained position.* Then (Tait's *Quaternions*, 3rd ed., § 507) the force due to stress on this area will be $\phi\omega$, where ϕ is a linear vector function not necessarily self-conjugate. ϕ is a function of ρ', or of ρ only, and does not in any way depend on ω. The force and the couple per unit volume of the strained body due to this stress are respectively (*Mess. of Math.*, vol. xiv. p. 29) $\phi_1\nabla_1'$ (or $\phi\Delta'$, as it might in accordance with the meaning of Δ, explained on p. 104 above, be written) and $V\zeta\phi\zeta$ (or $V\nabla_1'\phi\rho_1'$ or $V\nabla_1\phi\rho_1$ as it might be indifferently written.) Let now $U\nu', ds'$ stand for the unit normal and element of surface at a point of the boundary of the portion of the body considered, in its strained state. Let also $d\varsigma'$ stand for the strained volume of the element $d\varsigma$. Then noting that by Tait's *Quaternions*, 3rd ed., § 384, the rotation of the element due to the additional displacement is $V\nabla'\delta\rho'/2$, we see that the last equation gives

$$\iiint \delta w d\varsigma = -\iint S\delta\rho'\phi U\nu' ds' + \iiint S\delta\rho'\phi_1\nabla_1' d\varsigma' + \iiint S\epsilon\nabla'\delta\rho' d\varsigma',$$

where ϵ is put for $V\zeta\phi\zeta/2$, and $\therefore$ (equation (5) above).

$$\phi = \bar{\phi} + V\epsilon(\ ) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15),$$

where $\bar{\phi}$ stands for the pure part of ϕ.

Transforming now the surf. int. into a vol. int. by equation (3) above, we have

$$\begin{aligned}\iint S\delta\rho'\phi U\nu' ds' &= \iiint S\delta\rho'\phi\Delta' d\varsigma' \\ &= \iiint (S\delta\rho_1'\phi\nabla_1' + S\delta\rho'\phi_1\nabla_1') d\varsigma'.\end{aligned}$$

Combining this with the other volume integrals, and noting that

$$-S\delta\rho_1'\phi\nabla_1' + S\epsilon\nabla_1'\delta\rho_1' = -S\delta\rho_1'\bar{\phi}\nabla_1',$$

we get

$$\iiint \delta w d\varsigma = -\iiint S\delta\rho_1'\bar{\phi}\nabla_1' d\varsigma' \quad . \quad . \quad . \quad . \quad (16).$$

There is an important result that flows at once from this equation, true whether the strain be small or great, and which, I believe, has not hitherto been noticed. Into the expression just obtained for

the variation of the pot. en., ϕ does not enter in all its generality. A linear vector function, such as ϕ, can only be split up in one way into what may be called a pure part, $\bar{\phi}$, and a rotational part, $V\epsilon(\ )$. For the first part 6, and for the last 3, independent scalars must be assigned, and it is only the first 6 that have anything to do with the pot. en. Expressed in physical language:—*A stress can only be split up in one way, into two stresses, of which the first is an ordinary stress, producing no couple per unit volume, and the second is a couple-stress. The latter is quite independent of the pot. en.* Here, by a "couple-stress," is meant a stress which produces on any interface, whatever be the direction of its normal, a tangential force. Shortly stated, the above may be put:—*The part of the stress to which the couple per unit of volume is due, is independent of the pot. en.* This is strictly analogous to the well-known corresponding strain theorem that the rotation of an element is independent of the pot. en.*

We may anticipate here by saying that this part of the stress is therefore also independent of the strain, though of course other means enable us to determine it. In fact, in order that an element should not have infinite angular acceleration, it is easy to see that on the whole it must be subject to zero couple per unit volume. In other words, if $\mathfrak{M}$ be the given external couple per unit volume of the unstrained body

$$\mathfrak{M} + 2m\epsilon = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

is the equation which gives the part of ϕ we have called ϵ. Here m stands for $d\varsigma'/d\varsigma$, so that by equations (9) and (7) above

$$\left.\begin{aligned} 6m &= S\zeta_1\zeta_2\zeta_3 S\chi\zeta_1\chi\zeta_2\chi\zeta_3 = S\zeta_1\zeta_2\zeta_3 S\chi'\zeta_1\chi'\zeta_2\chi'\zeta_3 \\ &= S\zeta_1\zeta_2\zeta_3 S\psi\zeta_1\psi\zeta_2\psi\zeta_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \\ &= S\nabla_1\nabla_2\nabla_3 S\rho'_1\rho'_2\rho'_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \end{aligned}\right\} \quad . \quad . \quad (18).$$

If $\mathfrak{F}$ be the given external force per unit volume of the unstrained body, we must have for equilibrium

$$\mathfrak{F} + m\phi_1\nabla'_1 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19),$$

or

$$\mathfrak{F} + m(\bar{\phi}_1\nabla'_1 - V\nabla'\epsilon) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (20).$$

* That there is at least very grave doubt whether any such thing as a molecular couple, and therefore that a stress-couple exists (even in the case of magnetism), I hope to show on some future occasion. It is well to learn, however, the nature of the phenomenon, if it *possibly* exist.

This gives us a very simple way of dealing with the external couple when the strains are small. For in that case we may put $m=1$ and $\nabla' = \nabla$, when the equations become

$$\mathfrak{M} + 2\epsilon = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21),$$

$$\mathfrak{F} + \overline{\phi}\Delta - \mathrm{V}\nabla\epsilon = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22),$$

or, instead of the last,

$$(\mathfrak{F} + \tfrac{1}{2}\mathrm{V}\nabla\mathfrak{M}) + \overline{\phi}\Delta = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23),$$

so that the mathematical problem is the same as if there were no external couple, but instead of the given force $\mathfrak{F}$, there were the force $\mathfrak{F} + \frac{1}{2}\mathrm{V}\nabla\mathfrak{M}$. If any part of the given data consist of surface tractions, we must add that the given surface traction per unit surface $\mathfrak{F}_s$ must be replaced by $\mathfrak{F}_s - \frac{1}{2}\mathrm{VU}\nu\mathfrak{M}$, where $\mathrm{U}\nu$ is the unit normal at the point.

Returning to the consideration of equation (16), we see that if the portion considered be limited to the element $d\varsigma$, we obtain

$$\delta w = -m\mathrm{S}\delta\rho_1'\overline{\phi}\nabla_1' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24).$$

Before proceeding further, we must consider the strain a little more closely. Let χ be Professor Tait's (*Quaternions*, 3rd ed., § 384) strain function, so that

$$\chi\omega = -\mathrm{S}\omega\nabla . \rho' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25).$$

The physical meaning of χ may be thus explained. Let ω be the vector coordinate before strain of any point P, very near to another point O, relatively to the latter; then $\chi\omega$ is the coordinate of the strained position of P relative to the strained position of O. In symbols

$$d\rho' = \chi d\rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26).$$

From this equation we may at once deduce the expression for ∇' in terms of ∇ and conversely. For

$$\mathrm{S}d\rho\nabla = \mathrm{S}d\rho'\nabla' = \mathrm{S}\chi d\rho\nabla' = \mathrm{S}d\rho\chi'\nabla'$$

$\therefore$ since $d\rho$ is perfectly arbitrary

$$\nabla = \chi'\nabla' \text{ or } \nabla' = \chi'^{-1}\nabla \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

We have thus from equation (24)

$$\delta w = -m\mathrm{S}\delta\rho_1'\overline{\phi}\chi'^{-1}\nabla_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (28).$$

Now

$$\delta\chi\omega = -\delta\rho'_1 S\omega\nabla_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29).$$

Hence we see from equation (7) that in any expression, linear both in ∇_1 and $\delta\rho'_1$, such as the last expression for δw, we may substitute instead of these two ζ, $\delta\chi\zeta$ respectively. Hence

$$\delta w = -mS\delta\chi\bar{\zeta}\phi\chi'^{-1}\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30).$$

This expresses δw in terms of the variation of strain. It is convenient to modify the last equation by means of equation (6). Applying the rule given in connection with that equation, and changing $\zeta, \chi'^{-1}\zeta$ into $\chi^{-1}\zeta, \zeta$ respectively, we get

$$\delta w = -mS\delta\chi\chi^{-1}\zeta\bar{\phi}\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31).$$

Suppose, now * that the strain χ is made up of a pure strain ψ, followed by a rotation of $q(\;)q^{-1}$, so that

$$\chi\omega = q\psi\omega q^{-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32).$$

Then it is easy to prove that

$$\delta\chi\omega = 2VV\delta qq^{-1}.\chi\omega + q\delta\psi\omega q^{-1}.$$

Substituting in the last expression for δw, we get

$$\delta w/m = -2S.V\delta qq^{-1}.\zeta\bar{\phi}\zeta - Sq\delta\psi\chi^{-1}\zeta q^{-1}\bar{\phi}\zeta.$$

The first term on the right is zero, $\because V\zeta\bar{\phi}\zeta = 0$. That δq should disappear from the expression for δw is, of course, what we should expect. It is, however, well to show that this follows as a mathematical consequence of our fundamental assumptions. We now have

$$\begin{aligned}
\delta w &= -mS\delta\psi\chi^{-1}\zeta q^{-1}\bar{\phi}\zeta q \\
&= -mS\delta\psi\psi^{-1}(q^{-1}\zeta q)q^{-1}\bar{\phi}\zeta q \\
&\qquad \text{[by substituting for } \chi^{-1} \text{ in terms of } \psi \text{ and } q\text{]} \\
&= -mS\delta\psi\psi^{-1}\zeta q^{-1}\bar{\phi}(q\zeta q^{-1})q \\
&\qquad \text{[by substituting } \zeta, q\zeta q^{-1} \text{ for } q^{-1}\zeta q, \zeta \text{ respectively]} \\
&= -mS\delta\psi\psi^{-1}\zeta\varpi\zeta
\end{aligned}$$

* See Tait's *Quaternions*, 3rd ed., § 381, where it is shown how to determine both ψ and q in terms of χ.

where ϖ is a self-conjugate linear vector function of a vector defined by the equation

$$\varpi\omega = q^{-1}\overline{\phi}(q\omega q^{-1})q \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33).$$

Substituting $\zeta, \psi^{-1}\zeta$ for $\psi^{-1}\zeta, \zeta$ respectively in the last expression for δw, we finally get

$$\delta w = -m\mathrm{S}\delta\psi\zeta\varpi\psi^{-1}\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34).$$

Thus the only infinitesimal appearing in δw is $\delta\psi$. It follows that w can only be a function of the pure strain ψ. This is not an obvious truth, as I have before remarked. Assuming it now, we have by equation (13)

$$\delta w = -\mathrm{S}\delta\psi\zeta_{\psi}\triangleleft w\zeta .$$

Comparing this with the last equation, and noticing that $\delta\psi$ is a perfectly arbitrary self-conjugate linear vector function of a vector, we see (p. 103 above) that

$$2_{\psi}\triangleleft w = m(\varpi\psi^{-1} + \psi^{-1}\varpi) \quad . \quad . \quad . \quad . \quad . \quad . \quad (35),$$

$\because \frac{1}{2}(\varpi\psi^{-1} + \psi^{-1}\varpi)$ is the pure part of $\varpi\psi^{-1}$. The last equation can be easily shown to lead to

$$\left.\begin{aligned} m\varpi\omega &= {}_{\psi}\triangleleft w\psi\omega + \mathrm{V}\theta\psi\omega \quad . \quad . \quad . \\ \text{where} \qquad \theta &= (\psi + \mathrm{S}\zeta\psi\zeta)^{-1}\mathrm{V}\zeta_{\psi}\triangleleft w\psi\zeta \quad . \end{aligned}\right\} \quad . \quad . \quad . \quad (36).$$

This, with equation (33) above, completes the present problem of expressing the stress $\overline{\phi}$ explicitly in terms of the strain q and ψ.

ϖ can be easily shown to be that stress which $\overline{\phi}$ becomes when the body is rotated by the operator $q^{-1}(\ )q$, without altering the force exerted across any interface of the body. We thus see why it is ϖ and not $\overline{\phi}$ which bears the simplest relation to ψ.

$\phi\omega$ or $\overline{\phi}\omega + \mathrm{V}\epsilon\omega$, where ϵ is perfectly arbitrary so far as the strain is concerned, is the force exerted on the *strained* area ω. This last would more properly be denoted by ω'. Calling it ω', and denoting by ω the same vector area before strain, we have *

$$\omega' = m\chi'^{-1}\omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (37).$$

* By Tait's *Quaternions*, 3rd ed., §§ 157, 158, we have $\mathrm{V}\chi\mu\chi\nu = m\chi'^{-1}\mathrm{V}\mu\nu$. If μ, ν be taken as the conterminous edges of a small parallelogram in the unstrained state $\mathrm{V}\mu\nu$ will be its vector area; $\chi\mu$, $\chi\nu$ will be the edges of the strained parallelogram, and $\mathrm{V}\chi\mu\chi\nu$ its vector area.

Hence the force $\phi\omega'$ becomes $m\phi\chi'^{-1}\omega = m\bar{\phi}\chi'^{-1}\omega + m\mathrm{V}\epsilon\chi'^{-1}\omega$. Thus we see that the force on an elementary area, which before strain is ω, is a linear vector function of ω, but even in the case when there is no molecular couple, this function is not in general (large strain) self-conjugate. If there be no rotation, this force

$$\begin{aligned} &= m\varpi\psi^{-1}\omega + m\mathrm{V}\epsilon\psi^{-1}\omega \\ &= {}_{\psi}\mathrm{ɑ}w\omega + \mathrm{V}\theta\omega + m\mathrm{V}\epsilon\psi^{-1}\omega\,. \end{aligned}$$

If now the rotation take place this force merely rotates with the body, and we get for the force $\tau\omega$ on the area, due to the strain $q\psi(\ )q^{-1}$,

$$\tau\omega = q({}_{\psi}\mathrm{ɑ}w\omega + \mathrm{V}\theta\omega + m\mathrm{V}\epsilon\psi^{-1}\omega)q^{-1}. \quad . \quad . \quad . \quad (38).$$

It is not hard to see from the above that the couple per unit volume of the unstrained body is $2mq\epsilon q^{-1}$. The force per unit volume of the unstrained body can be shown by means of equation (3) to be $\tau\Delta$. From these we can write down equations of motion in which ψ occurs. To obtain equations of motion in which only ρ' and its derivatives occur explicitly we must adopt a different method.

Consider w a given function, not of ψ as above, but of ψ^2 or $\chi'\chi$ (Tait's *Quaternions*, 3rd ed., § 381). Let

$$\Psi\omega = \psi^2\omega = \chi'\chi\omega = \nabla_1\mathrm{S}\omega\nabla_2\mathrm{S}\rho_1'\rho_2' \quad . \quad . \quad . \quad . \quad (39).$$

In assuming that w is given as an explicit function of the coordinates of Ψ, we are following Thomson and Tait, for these coordinates will be found to be the A,B,C,a,b,c of Appendix C of their *Nat. Phil.*

To see the enormous advantage of employing quaternions in such questions as the present, it is only necessary to compare the processes and results of the present investigation with theirs. The results below are considerably more general than theirs, and yet how much less cumbrous.

By the methods already so often applied, it is easy to prove both the following identities :—

$$\begin{aligned} \mathrm{S}\delta\chi\zeta\phi\chi'^{-1}\zeta &= \mathrm{S}\chi'\delta\chi\zeta\chi^{-1}\bar{\phi}\chi'^{-1}\zeta \\ &= \mathrm{S}\delta\chi'\chi\zeta\chi^{-1}\bar{\phi}\chi'^{-1}\zeta. \end{aligned}$$

Thus we see from equation (30) that

$$\frac{\delta w}{m} = -\tfrac{1}{2}\mathrm{S}(\chi'\delta\chi + \delta\chi'\chi)\zeta\chi^{-1}\bar{\phi}\chi'^{-1}\zeta$$
$$= -\tfrac{1}{2}\mathrm{S}\delta\Psi\zeta\chi^{-1}\bar{\phi}\chi'^{-1}\zeta .$$

But we also have by equation (13) above

$$\delta w = -\mathrm{S}\delta\Psi\zeta_{\Psi}\mathrm{ʠ}w\zeta .$$

Hence from p. 104 above we see that

$$2_{\Psi}\mathrm{ʠ}w = m\chi^{-1}\bar{\phi}\chi'^{-1},$$

or

$$\bar{\phi} = \frac{2}{m}\chi_{\Psi}\mathrm{ʠ}w\chi', \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40).$$

(It is easy from here to go back and prove all our previous results over again. Perhaps this, in fact, would be the shortest method, but it would not be the most natural. To do so it is only necessary to notice that since $\mathrm{S}\delta\psi\zeta_{\psi}\mathrm{ʠ}\zeta = \mathrm{S}\delta\Psi\zeta_{\Psi}\mathrm{ʠ}\zeta$, it can be proved that ${}_{\psi}\mathrm{ʠ} = {}_{\Psi}\mathrm{ʠ}\psi + \psi_{\Psi}\mathrm{ʠ}$ where the differentiations on the right are not to act upon ψ.)

Substitute from equation (27) for ∇' in the equations (17) and (20) of equilibrium. Thus

$$\mathfrak{F} - \frac{mm_1^{-1}}{2}\mathrm{V}\mathfrak{M}_1\chi'^{-1}\nabla_1 + m\bar{\phi}_1\chi^{-1}\nabla_1 = 0 .$$

Noticing that since by equation (11)

$$2m\chi'^{-1}\omega = -\mathrm{V}\rho'_1\rho'_2\mathrm{S}\omega\nabla_1\nabla_2 ,$$

we have

$$m\chi'^{-1}\Delta = 0 ,$$

this last equation can be written

$$\mathfrak{F} - \tfrac{1}{2}\mathrm{V}\mathfrak{M}\chi'^{-1}\Delta + m\bar{\phi}\chi'^{-1}\Delta = 0 .$$

Substituting now for $\bar{\phi}$ from equation (40) we have

$$\mathfrak{F} - \tfrac{1}{2}\mathrm{V}\mathfrak{M}\chi'^{-1}\Delta + 2\chi_{\Psi}\mathrm{ʠ}w\Delta = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (41),$$

or

$$\mathfrak{F} + \tfrac{3}{2}\left(\frac{\mathrm{V}\mathfrak{M}\mathrm{V}\rho'_1\rho'_2}{\mathrm{S}\nabla_3\nabla_4\nabla_5\mathrm{S}\rho'_3\rho'_4\rho'_5}\right)\mathrm{S}\Delta\nabla_1\nabla_2 - 2\rho'_1\mathrm{S}\nabla_{1\Psi}\mathrm{ʠ}w\Delta = 0 \quad (42).$$

This is the equation of equilibrium of an elastic body (solid or fluid) subjected to an external force and couple per unit volume of the unstrained body $\mathfrak{F}$ and $\mathfrak{M}$ respectively. For the corresponding equation of motion we have to equate the left member of this equation to $D\ddot{\rho}'$, where D is the density of the body at the point in the standard state.

In the case considered by Thomson and Tait (*Nat. Phil.*, App. C.), both $\mathfrak{F}$ and $\mathfrak{M}$ are zero, and our equation takes the very simple form

$$\rho_1{}'S\nabla_{1\Psi}\mathfrak{a}w\Delta = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

the *exact* quaternion equivalent of their three equations (7).*

In connection with equations (41) and (42), it should be observed that

$$\tau\omega = -\tfrac{1}{2}V\mathfrak{M}\chi'^{-1}\omega + 2\chi_{\Psi}\mathfrak{a}w\omega \quad . \quad . \quad . \quad . \quad (44)$$

where τ has the same meaning as in equation (38).

The next few applications will be of an extremely simple nature, and will be confined to work already well known in its Cartesian form.

We now assume, as is usual, that the strains are small, and that there is no external couple, and therefore no stress couple. We deduce our equations as particular cases of the above, though, of course, if the present were our sole object, we could adopt a much simpler process. We may put $q=1$, $\phi=\bar{\phi}=\varpi$, $2\psi=\chi+\chi'$, and $\omega'=\omega$. Also $V\zeta_{\psi}\mathfrak{a}w\psi\zeta = V\zeta_{\psi}\mathfrak{a}w\zeta = 0$, and $\therefore\ \theta$ of equations (36) $=0$. Thus equation (36) gives

$$\varpi = {}_{\psi}\mathfrak{a}w \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45).$$

It is worth while giving one of these for comparison. I may remark that many of the results arrived at above, although quite simple enough in their quaternion form to be manageable, and therefore useful, become so extraordinarily complicated when translated into Cartesian notation as to be utterly unmanageable and useless. The equation referred to is

$$\frac{d}{dx}\left\{2\frac{dw}{dA}\left(\frac{da}{dx}+1\right)+\frac{dw}{db}\frac{da}{dz}+\frac{dw}{dc}\frac{da}{dy}\right\}$$

$$+\frac{d}{dy}\left\{2\frac{dw}{dB}\frac{da}{dy}+\frac{dw}{da}\frac{da}{dz}+\frac{dw}{dc}\left(\frac{da}{dx}+1\right)\right\}$$

$$+\frac{d}{dz}\left\{2\frac{dw}{dC}\frac{da}{dz}+\frac{dw}{da}\frac{da}{dy}+\frac{dw}{db}\left(\frac{da}{dx}+1\right)\right\}=0.$$

Since we are dealing with small strains, it is convenient to alter the notation slightly. Instead of our previous χ and ψ we shall now write $1+\chi$ and $1+\psi$ respectively, so that both χ and ψ are small, and ψ is the pure part of χ. And, further, we shall write $\rho'=\rho+\eta$, so that η is the small displacement. Thus

$$\chi\omega = -S\omega\nabla.\eta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46)$$

$$\psi\omega = -\tfrac{1}{2}(\eta_1 S\omega\nabla_1 + \nabla_1 S\omega\eta_1) \quad . \quad . \quad . \quad . \quad (47).$$

Since the strain ψ is small, the stress ϖ, *i.e.*, ${}_{\psi}\mathrm{C}w$ is linear in ψ, and $\therefore$ w is quadratic. Now, for any such quadratic expression as can be easily proved

$$w = -\tfrac{1}{2}S\psi\zeta\,{}_{\psi}\mathrm{C}w\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (48),$$

$\therefore$ from equation (45) we have

$$w = -\tfrac{1}{2}S\psi\zeta\varpi\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (49).$$

Also w, being quadratic in ψ, is, if regarded as a function of ϖ, quadratic in it. Hence

$$w = -\tfrac{1}{2}S\varpi\zeta\,{}_{\varpi}\mathrm{C}w\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad (50),$$

and $\therefore$ by the last equation and p. 104 above,

$$\psi = {}_{\varpi}\mathrm{C}w \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51).$$

Instead of regarding w as a function of ψ or of ϖ, it is perhaps simpler, from the mathematical point of view, to start with assuming it a given function of the first space derivatives of η. Let, in fact,

$$w = w(\nabla_1,\eta_1,\nabla_2,\eta_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (52)$$

where $w(\alpha,\beta,\gamma,\delta)$ is a scalar function of the vectors α, β, γ, δ, which is (1) linear in *each* of its constituents; (2) symmetrical in α and β, and also in γ and δ; (3) such that the pair α, β may be interchanged with the pair γ, δ without altering the value of the function. (If this last is not true in the first form of w chosen, it may be made so by writing $\tfrac{1}{2}w(\alpha,\beta,\gamma,\delta)+\tfrac{1}{2}w(\gamma,\delta,\alpha,\beta)$ instead of $w(\alpha,\beta,\gamma,\delta)$, as this does not affect equation (52).) Such a function can be proved to involve twenty-one independent scalar constants, which is the number also required to determine an arbitrary homogeneous quadratic function of the six coordinates of ψ.

We may from this form of w at once go back to that in terms of ψ by means of equation (8) above. Thus,

$$w = w(\zeta_1, \psi\zeta_1, \zeta_2, \psi\zeta_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53),$$

or, again, by equation (7),

$$w = w(\zeta_1, \chi\zeta_1, \zeta_2, \chi\zeta_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (54).$$

Hence by substituting $-\zeta S\zeta_1\psi\zeta$ for $\psi\zeta_1$, we get

$$-\tfrac{1}{2}S\psi\zeta\varpi\zeta = w = -S\psi\zeta\{\zeta_1 w(\zeta_1, \zeta, \zeta_2, \psi\zeta_2)\},$$

and $\therefore$ by p. 104

$$\varpi\omega = 2\zeta w(\zeta, \omega, \zeta_1, \psi\zeta_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (55),$$

or, again, by equation (8),

$$\varpi\omega = 2\zeta w(\zeta, \omega, \nabla_1, \eta_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad (56).$$

The equation (23) of equilibrium thus becomes in this case

$$\mathfrak{F} + 2\zeta w(\zeta, \Delta, \nabla_1, \eta_1) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (57)$$

Thus in the case of isotropic bodies in which c is the compressibility and n the rigidity, we have (*Mess. of Math.*, vol. xiv. pp. 30, 31)

$$\varpi\omega = 2n\psi\omega - \left(c - \frac{2}{3}n\right)\omega S\zeta\psi\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad (58),$$

$$\psi\omega = \frac{1}{2n}\varpi\omega + \left(\frac{1}{6n} - \frac{1}{9c}\right)\omega S\zeta\varpi\zeta \quad . \quad . \quad . \quad . \quad . \quad (59).$$

Thus from these equations and equation (49)

$$\left.\begin{aligned} w &= -n\psi\zeta\psi\zeta + \left(\frac{c}{2} - \frac{n}{3}\right)S^2\zeta\psi\zeta \\ &= -\frac{1}{4n}\varpi\zeta\varpi\zeta - \left(\frac{1}{12n} - \frac{1}{18c}\right)S^2\zeta\varpi\zeta \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (60).$$

Again, from the first of these equations and equation (8) we have

$$w = -nS\nabla_1\psi\eta_1 + \left(\frac{c}{2} - \frac{n}{3}\right)S^2\nabla\eta,$$

or

$$2w = nS\nabla_1\eta_2 S\nabla_2\eta_1 + nS\nabla_1\nabla_2 S\eta_1\eta_2 + \left(c - \frac{2}{3}n\right)S^2\nabla\eta \quad . \quad (61),$$

and from equation (56)

$$\varpi\omega = -nS\omega\nabla.\eta - n\nabla_1 S\omega\eta_1 - (m-n)\omega S\nabla\eta \quad . \quad . \quad (62),$$

where m stands for $c+\frac{n}{3}$. This last may be derived in a great many other ways still more simple.

The equation of equilibrium thus becomes

$$\mathfrak{F}=n\nabla^2\eta+m\nabla S\nabla\eta \quad . \quad . \quad . \quad . \quad . \quad (63).$$

As a final application in the theory of elasticity let us consider St Venant's torsion problem from a quaternion point of view. Let r, ϕ, z be ordinary columnar coordinates whose axis is parallel to the generating lines of the cylinder. Let λ, μ, ν be unit vectors in the directions of dr, $d\phi$, dz respectively, so that

$$\nabla=\lambda\frac{d}{dr}+\frac{\mu}{r}\frac{d}{d\phi}+\nu\frac{d}{dz}.$$

It is required to determine v a scalar function of r and ϕ, so that η given by the equation

$$\eta=\tau(zr\mu+v\nu) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (64),$$

where τ is a given small scalar constant, may satisfy (1) equation (63) of equilibrium, and (2) the equation

$$0=\varpi\omega=-nS\omega\nabla.\eta-n\nabla_1 S\omega\eta_1-(m-n)\omega S\nabla\eta$$

at every point of the curved surface; ω in this case standing for the normal at the point. Q having the same general meaning as on p. 104 above, we have

$$Q(\nabla_1,\eta_1)=\tau\{z[Q(\lambda,\mu)-Q(\mu,\lambda)]+rQ(\nu,\mu)+Q(\nabla v,\nu)\} \quad (65).$$

In the case when Q is symmetrical in its constituents this takes the simple form

$$Q(\nabla_1,\eta_1)=\tau\{rQ(\nu,\mu)+Q(\nabla v,\nu)\} \quad . \quad . \quad . \quad . \quad (66).$$

From the first of these we have

$$\begin{aligned}\nabla\eta&=\tau\{(2z\nu-r\lambda)+\nabla v\nu\}\\&=\tau\{\nabla(z^2-\tfrac{1}{2}r^2)+\nabla v\nu\}\end{aligned}$$

so that $S\nabla\eta=0$ and $\nabla^2\eta=\nu\nabla^2 v$. Thus equation (63) becomes

$$\nabla^2 v=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (67).$$

From equations (62) and (66) above, we see that in the present case the stress is given by

$$\varpi\omega=-n\tau\{r(\mu S\omega\nu+\nu S\omega\mu)+(\nu S\omega\nabla v+\nabla vS\omega\nu)\} \quad . \quad (68),$$

and therefore consists of two shears; the first of magnitude $n\tau r$, with faces perpendicular to μ and ν, and the second of magnitude $n\tau T\nabla v$, with faces perpendicular to ν and ∇v. Assuming ω to be the normal at a point of the curved surface, and therefore perpendicular to ν, we have

$$0 = rS\omega\mu + S\omega\nabla v$$
$$= -\tfrac{1}{2}S\nu\omega\nabla(r^2) + S\omega\nabla v.$$

Thus

$$\frac{dv}{dn} = \frac{d}{dl}\left(\frac{r^2}{2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (69),$$

where d/dn denotes differentiation along the normal outwards, and d/dl differentiation in the positive direction round the boundary.

The surface traction on the plane end

$$= \varpi\nu = n\tau(r\mu + \nabla v).$$

Hence the total moment round the axis

$$= n\tau \iint (r^2 - rS\mu\nabla v)dA$$
$$= n\tau\left(I + \iint \frac{dv}{d\phi}dA\right),$$

where dA is an element of area of the cross-section, and I is the moment of inertia of the cross-section round the axis. Thus the torsional rigidity is, as usual, $n\left(I + \iint \frac{dv}{d\phi}dA\right)$. We leave the problem here to the theories of complex variables and Fourier's theorem.

It is in the general theories of electrostatics and electromagnetism that I have found the methods now being defended the most powerful. I have been led to believe that there is in all the accepted theories which are based on general dynamical reasoning an error of a somewhat serious character. I have also been led to a considerable modification and extension of Poynting's theories. There are two reasons against giving these here. I have been told that this preliminary apology, as it may be termed, for my methods should be as short and simple as possible. Moreover, the greater part of my notes on this subject are at present inaccessible. I therefore limit myself in this branch to a single example.

Maxwell has not investigated what are the general mechanical results of his electrostatic theory for crystallised dielectrics.

According to him, the properties of the medium depend on six independent constants for each point, called the coefficients of spec. ind. cap. These coefficients will themselves be functions of the state of the medium, and therefore in particular of its strain. Assume with Maxwell that

$$\mathfrak{E} = -\nabla v, \qquad \mathfrak{D} = \frac{K}{4\pi}\mathfrak{E} \quad . \quad . \quad . \quad . \quad . \quad . \quad (70),$$

where K is not a mere *scalar*, but a *self-conjugate linear vector function of a vector.* K is itself a function of the position of a point and also of the strain at the point. Here v is for obvious reasons put for Maxwell's V. Assume further, that if W be the pot. en. of the field; D,σ be the volume and surface density of electricity; and the rest of the notation be identical with Maxwell's,

$$\left.\begin{aligned} 2W &= \iint v\sigma ds + \iiint v D d\varsigma \\ &= -\iiint S\mathfrak{D}\mathfrak{E} d\varsigma \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (71),$$

and * ∴

$$W = \iint v\sigma ds + \iiint v D d\varsigma + \tfrac{1}{2}\iiint S\mathfrak{D}\mathfrak{E} d\varsigma \quad . \quad . \quad . \quad (72),$$

$$D = -S\nabla\mathfrak{D} \qquad \sigma = [S\mathfrak{D}U\nu]_a + [S\mathfrak{D}U\nu]_b \quad . \quad . \quad (73),$$

the last occurring only at a surface of discontinuity in $\mathfrak{D}$, $U\nu$ pointing *away* from the region of the corresponding $\mathfrak{D}$, and the two regions bounded by the surface being denoted by the suffixes a and b. In future, such expressions as $[\ ]_a + [\ ]_b$ will, for brevity, be written $[\ ]_{a+b}$. All our integrals are supposed to extend throughout all space; though, as $K=0$ for conductors, these may be excluded. The boundaries of space are the surface at infinity and all surfaces of discontinuity in $\mathfrak{D}$ or $\mathfrak{E}$.

To find the mechanical results flowing from the above assumptions, let ρ be the *present* (whether strained or not) vector coordinate of any point, and let the medium be (additionally) strained by a small displacement $\delta\eta$, vanishing at infinity. Let δW be the increment in W Then if δW can be expressed in the form

$$\delta W = -\iiint S\delta\eta_1\phi\nabla_1 d\varsigma \quad . \quad . \quad . \quad . \quad . \quad . \quad (74),$$

* In taking this for the form of W, and operating upon it as follows, we are following Helmholtz for the particular case when K is a mere scalar. See *Wiss. Abh.*, equation (2*d*), p. 805. For the various assumptions above see Maxwell's *Electricity and Magnetism*, part i.

we shall have the following expressions for $\mathfrak{F}$ and $\mathfrak{F}_s$ the forces per unit volume and surface respectively due to the electric system.

$$\mathfrak{F} = \phi\Delta \qquad \mathfrak{F}_s = -[\phi U\nu]_{a+b} \quad . \quad . \quad . \quad . \quad . \quad (75).$$

And, further, if ϕ be self-conjugate, both these forces will be explained by a stress ϕ, as can be seen by the above work on stress. For proof we have by equation (3) above

$$\delta W = -\iiint S\delta\eta_1\phi\nabla_1 d\varsigma = -\iint S\delta\eta\phi U\nu ds + \iiint S\delta\eta\phi_1\nabla_1 d\varsigma$$

where of course the element ds is taken twice, namely, once for the region on each side. But

$$\delta W = -\text{(work done by the system } \mathfrak{F}, \mathfrak{F}_s, \text{ of forces)}$$
$$= \iint S\mathfrak{F}_s\delta\eta ds + \iiint S\mathfrak{F}\delta\eta d\varsigma,$$

where the element ds is now only taken once. Equating coefficients of the arbitrary vector $\delta\eta$ we get the required equations.

To avoid difficulty at surfaces of discontinuity, δ when applied to a function of the position of a point must be thus defined. Suppose that by means of the displacement $\delta\eta$, any point is moved from P to P′. Then Q being the value of any function at P before the displacement, $Q + \delta Q$ will be the value at P′ after the displacement. δQ is thus in all cases a small quantity of the same order as $\delta\eta$. With this meaning of δ, $\delta\nabla$ is not $= 0$. To find it observe that

$$S(d\rho + \delta d\rho)(\nabla + \delta\nabla) = Sd\rho\nabla$$

but
$$\delta d\rho = -Sd\rho\nabla . \delta\eta$$

$\therefore$
$$Sd\rho\delta\nabla = Sd\rho\nabla_1 S\delta\eta_1\nabla$$

whence
$$\delta\nabla = \nabla_1 S\delta\eta_1\nabla \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (76),$$

which might have been derived from the equation (27) $\nabla' = \chi'^{-1}\nabla$.

Assuming that the strain due to $\delta\eta$ does not alter the charge of any portion of matter,

$$0 = \delta(Dd\varsigma) = \delta(\sigma ds) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (77).$$

To find δW, notice that

$$\delta d\varsigma = -d\varsigma S\nabla\delta\eta$$

and
$$4\pi\delta\mathfrak{D} = K\delta\mathfrak{E} + \delta K.\mathfrak{E},$$

and $\therefore$ $\quad \delta(S\mathfrak{D}\mathfrak{E}d\varsigma) = \left(2S\mathfrak{D}\delta\mathfrak{E} - S\mathfrak{D}\mathfrak{E}S\nabla\delta\eta + \frac{1}{4\pi}S\mathfrak{E}\delta K\mathfrak{E}\right)d\varsigma\,.$

Also
$$\iiint \delta v.\mathrm{D}d\varsigma + \iint \delta v.\sigma d\varsigma$$
$$= -\iiint \delta v S\nabla\mathfrak{D}d\varsigma + \iint \delta v S U\nu\mathfrak{D}d\varsigma \text{ [equations (73)]}$$
$$= \iiint S\mathfrak{D}\nabla\delta v d\varsigma \qquad \text{[equation (3)]}\,.$$

Hence
$$\delta W = \iiint d\varsigma\left\{S\mathfrak{D}(\nabla\delta v + \delta\mathfrak{E}) - \tfrac{1}{2}S\mathfrak{D}\mathfrak{E}S\nabla\delta\eta + \frac{1}{8\pi}S\mathfrak{E}\delta K\mathfrak{E}\right\}.$$

But
$$\nabla\delta v + \delta\mathfrak{E} = -\delta\nabla\,.\,v = -\nabla_1 S\delta\eta_1\nabla v\,.$$

Hence
$$\delta W = -\iiint S\delta\eta_1(\tfrac{1}{2}\nabla_1 S\mathfrak{D}\mathfrak{E} - \mathfrak{E}S\nabla_1\mathfrak{D})d\varsigma + \frac{1}{8\pi}\iiint S\mathfrak{E}\delta K\mathfrak{E}d\varsigma\,.$$

The increment δK is conveniently considered as consisting of two parts—first, δK_r, due to the rotation of the body; and second, δK_s, due to the change of shape, *i.e.*, the pure strain. If the rotation vector due to $\delta\eta$ be ϵ, *i.e.*, if any vector ω become $\omega + V\epsilon\omega$, the result of operating on $\omega + V\epsilon\omega$ by $K + \delta K_r$ must be the same as first operating on ω by K and then rotating. In symbols
$$(K + \delta K_r)(\omega + V\epsilon\omega) = K\omega + V\epsilon K\omega\,,$$
whence
$$\delta K_r\omega = V\epsilon K\omega - KV\epsilon\omega\,.$$
Thus
$$S\mathfrak{E}\delta K_r\mathfrak{E} = S\mathfrak{E}\epsilon K\mathfrak{E} - S\mathfrak{E}KV\epsilon\mathfrak{E} = 8\pi S\epsilon\mathfrak{D}\mathfrak{E}\,,$$

whence giving ϵ its value, $\frac{1}{2}V\nabla\delta\eta$,
$$\frac{1}{8\pi}S\mathfrak{E}\delta K_r\mathfrak{E} = \tfrac{1}{2}S\nabla\delta\eta V\mathfrak{D}\mathfrak{E}\,.$$

If we put w for the pot. en. per unit volume we have
$$w = -\tfrac{1}{2}S\mathfrak{D}\mathfrak{E} = -\frac{1}{8\pi}S\mathfrak{E}K\mathfrak{E} \quad . \quad . \quad . \quad . \quad (78).$$

K is a function of the independent variables ϵ and ψ, where ψ is the pure strain given by
$$\psi\omega = -\tfrac{1}{2}(\eta_1 S\omega\nabla_1 + \nabla_1 S\omega\eta_1).$$

Thus w may be regarded as a function of the independent variables $\mathfrak{E}$, ϵ, ψ, and we shall have

$$\frac{1}{8\pi}S\mathfrak{E}\delta K_s\mathfrak{E} = S\delta\psi\zeta_\psi \mathfrak{a} w\zeta = S\delta\eta_{1\psi}\mathfrak{a} w\nabla_1$$

by equations (13) and (8) above.

Thus

$$\delta W = -\iiint S\delta\eta_1(\tfrac{1}{2}\nabla_1 S\mathfrak{D}\mathfrak{E} - \mathfrak{E}S\nabla_1\mathfrak{D} + \tfrac{1}{2}V\nabla_1 V\mathfrak{D}\mathfrak{E} - {}_\psi\mathfrak{a} w\nabla_1)d\varsigma$$

or

$$\delta W = \iiint S\delta\eta_1(\tfrac{1}{2}V\mathfrak{D}\nabla_1\mathfrak{E} + {}_\psi\mathfrak{a} w\nabla_1)d\varsigma \quad . \quad . \quad . \quad (79).$$

Hence we see that

$$\mathfrak{F} = -\tfrac{1}{2}V\mathfrak{D}\Delta\mathfrak{E} - {}_\psi\mathfrak{a} w\Delta \quad . \quad . \quad . \quad . \quad . \quad . \quad (80)$$

$$\mathfrak{F}_s = [\tfrac{1}{2}V\mathfrak{D}U\nu\mathfrak{E} + {}_\psi\mathfrak{a} wU\nu]_{a+b} \quad . \quad . \quad . \quad . \quad . \quad (81),$$

and that these forces per unit volume and surface respectively can be supposed due to a stress ϕ given by

$$\phi\omega = -\tfrac{1}{2}V\mathfrak{D}\omega\mathfrak{E} - {}_\psi\mathfrak{a} w\omega \quad . \quad . \quad . \quad . \quad . \quad . \quad (82).$$

From this we see that the stresses in the electric field can only be determined when for the particular strain existing at any point forty-two scalar functions of that strain are known, viz., the six coefficients of specific inductive capacity and their thirty-six differential coefficients with respect to the six coefficients of pure strain.

The two parts of the stress ϕ (1) that which is independent of the variation of specific inductive capacity with strain, and (2) that which depends on this variation are conveniently considered separately.

The first is more general than Maxwell's, because we have not, as he does in this connection, assumed that $\mathfrak{D}$ is parallel to $\mathfrak{E}$. It consists of a tension in the direction bisecting the positive directions (or negative directions) of both $\mathfrak{D}$ and $\mathfrak{E}$, of magnitude $\tfrac{1}{2}T\mathfrak{D}T\mathfrak{E}$, an equal pressure in the direction bisecting the positive direction of either and the negative direction of the other, and a pressure at right angles to both, of magnitude $-\tfrac{1}{2}S\mathfrak{D}\mathfrak{E}$ or w. This stress, of course, reduces to Maxwell's when $\mathfrak{D}$ is parallel to $\mathfrak{E}$.

The other part of the stress $-{}_\psi\mathfrak{a} w = \frac{1}{8\pi}{}_\psi\mathfrak{a}_1 S\mathfrak{E}K_1\mathfrak{E}$ can be only

usefully considered when certain simplifying assumptions are made. In Professor J. J. Thomson's consideration of this subject (*Applications of Dynamics to Physics and Chemistry*, §§ 35 and 39), he not only assumes K to be a mere scalar both before and after strain, but he also does not consider the most general case of strain which involves 6 instead of 3 independent coefficients. If this last restriction had not been made, our 42 constants would have reduced to 7, and in his case they reduce to 4. In either of these cases the stress is simple enough, viz., $\frac{\mathfrak{E}^2}{8\pi\psi}\text{ᗡ}K$.*

* For other particular cases of the stress under consideration, see Helmholtz, *Wiss. Abh.*, i. 798 ; Korteweg, *Wied. Ann.*, ix. 48 ; Lorberg, *Wied. Ann.*, xxi. 300 ; Kirchoff, *Wied. Ann.*, xxiv. 52, xxv. 601.

On the Interaction of Longitudinal and Circular Magnetisations in Iron and Nickel Wires. (Second Note.) By Professor Cargill G. Knott.

(Read February 16, 1891.)

In a preliminary note communicated last July,* I drew attention to what seemed a novel property of iron wire under the combined influence of circular and longitudinal magnetisations. Similar experiments were subsequently tried with nickel, and similar results obtained. It appeared, however, that in some respects nickel behaved oppositely to iron. The first series of observations brought out the fact that a current along the nickel wire seemed to assist the acquiring, under a longitudinal magnetising force, of a polarity oppositely directed to the direction of the current.

Unfortunately the necessity of stopping work during the hot summer months postponed the discovery that much if not all of the supposed curious effect in iron and nickel was due to the existence of a twist in the wire. It should be mentioned that the wires were set up with great care, being first annealed, then brazed to terminal pieces, then annealed a second time under horizontal tension sufficient to keep them straight in a direction perpendicular to the magnetic meridian. To one of the terminals two copper wires, laid parallel to and on each side of the nickel or iron wire, were soldered; and the set of three wires was placed in position in suitably arranged grooves cut along the plane surface of a semi-cylinder of wood. The other half of the cylinder was then superposed so as to keep the wires firmly in position; and the whole arrangement was lifted from the place where the final annealing had been accomplished and inserted into its position in the heart of the magnetising coil. Exactly when the wire got twisted it is impossible to say. It must have been a small twist; but that it did acquire a permanent twist is sufficiently proved by later experiments in the months of October and November 1890.

In these later experiments a slightly different arrangement was adopted. The wire to be treated, after careful annealing, was

* See also *Phil. Mag.* for September 1890.

slipped through a glass tube a little longer than the internal metal wall of the tube on which the well-insulated magnetising coil was coiled. This metal wall was used as the return channel for the current, so that all possibility of an appreciable direct electro-magnetic effect of the circuit upon the magnetometer was quite excluded. The end of the iron or nickle wire nearer to the magnetometer was gripped vice-wise by a cleft metal plug of conical shape, which, when pushed into the end of the magnetising coil, established good pressure contacts between the end of the wire and the metal wall. The other end of the wire projected backwards out of the magnetising coil sufficiently to enable it to be clamped to a twisting gear. From this end, and from the neighbouring end of the tube wall, wires well insulated and well twisted together were led to the commutator connected with the battery.

It was only after a series of experiments, in which the effect mentioned in my earlier note was observed to take place sometimes in one way and sometimes in the other, that I came to the conclusion that there must be an original permanent twist in the wire. Thick wires showed comparatively small effects, steel wire showed the effect only when it was drawn thin, and so on. Nickel wires behaved in an especially confusing manner, even after the greatest care was taken to insert them untwisted into the magnetising coil. The twisting gear mentioned above was added to the apparatus so as to make a direct experiment upon the effect of a small voluntarily applied twist. That large twists might reasonably be expected to produce peculiar disturbances in the magnetic distribution under the combined influence of longitudinal and circular magnetisations will be at once admitted when it is remembered to what an extent twisting affects the result of either taken alone. I was not prepared, however, for *the pronounced influence exerted by even a small twist previously existing in the wire upon subsequently applied longitudinal and circular magnetisations.*

To prevent the possibility of such twists being inadvertently applied, the wire was, in the later experiments, annealed with a weight hanging free at the one end. This left the wire permanently magnetised under the influence of the earth's vertical field; but in the stronger cyclic field to which it became subjected the wire soon lost all trace of this original polarity. After being annealed the

wire was gently lowered without rotation by means of a screw until the weight came to rest on a shelf. The wire was then sharply cut a little above its lower end, the glass tube slipped over it, and a second severance made near its upper end. The glass tube with contained wire was next inserted into the magnetising coil, and the ends carefully clamped after the manner already indicated. In the following table the results of one experiment with the iron are given. The word "current" means the current along the wire; the word "field" means the longitudinal magnetising force to which the wire was subjected. A current is *positive* when it flows in the direction of the lines of force, of what is conventionally taken as the *positive* field—that is, in the experiments under consideration, towards the east. Under the column headed "range" is given the range of scale readings corresponding to the cyclic variation of field under the circumstances indicated. The column headed "polarity" contains the mean of the extreme scale readings.

For Iron Wire of Diameter 0·94 *mm.*

Current.	Field.	Range.	Polarity.
0	±	324	−6
+2·2	,,	175	−7·5
−2·2	,,	180	−7
0	,,	317	−4·5
0	,,	321	−2·5
+1·47	,,	208	−5
−1·47	,,	206	−4
0	,,	325	−7·5
+0·83	,,	275	−5·5
−0·83	,,	277	−6·5
+0·5	,,	287	−6·5
−0·5	,,	282	−7

Here, the only apparent effect of passing a current along the wire is to decrease the range of intensity due to a given cyclic variation of field. The susceptibility is markedly diminished, and the more so as the current is taken stronger. There is not the least evidence of an accumulated polarity changing sign with the current, as described in my first note.

In the next series of experiments the wire (current and field being both zero) was twisted right-handedly through an angle of 10° in a

length of 48 centimetres, or $12\frac{1}{2}$ minutes per centimetre length. The results obtained were as follows for this and other twists, all indicated in the first column :—

Twist.	Current.	Field.	Range.	Polarity.
+12′·5	0	±	343	+ 1·5
	+2·1	,,	195	+12·5
	−2·1	,,	197	−18·5
+25′	0	,,	350	−5
	+2·1	,,	195	+17·5
	−2·1	,,	193	−24·5
+37′·5	0	,,	338	−6
	+2·1	,,	168	+39
	−2·1	,,	167	−43·5
+12′·5	0	,,	355	+0·5
	+2·1	,,	202	−4
	−2·1	,,	202	−1
0	+2·1	,,	207	−1·5
	−2·1	,,	211	−3·5
−37·5	0	,,	357	+ 1·5
	+2·1	,,	205	−10·5
	−2·1	,,	206	+ 5

In Part II. of my paper on certain relations between magnetism and twist on twisted iron and nickel wires,* I have worked out in detail the changes of longitudinal polarity produced by twisting a wire when a current is passing along it, or by reversing the current along it when the wire is twisted. In the latter case, if the wire is twisted right-handedly (so that any line in it originally parallel to the axis becomes a right-handed screw), the longitudinal intensity is co-directional with the current in iron, anti-directional in nickel —a fact first established by Wiedemann. In the light of this fact, the experiments just described become intelligible. The sign of the polarity acquired is to a large extent determined by the twist in the wire. In the fourth series, in which the wire was untwisted

* Not yet published. See, however, a short paper on "Magnetic Priming and Lagging in Twisted Iron and Nickel Wires," *Journal of the College of Science, Imperial University, Japan*, vol. iii. (1889)—Abstract in Wiedemann's *Beiblätter*, vol. xiii.

back to its first stage of positive twist, there is a hint at a change in the law of the acquired polarity. It is obvious, however, that this is simply the result of torsional after-effect. The wire, in fact, has become elastically untwisted, although it has not become so as regards the relative positions of its end-sections. On continuing the untwisting past the original zero, we find that it is some time before a pronounced effect is produced. Even for the twist $-37'{\cdot}5$ the difference in the average polarities for the two directions of current attains to nothing like the first difference for the twist of $+37'{\cdot}5$. This comparative vanishing away of the polarity difference effect as the wire is partially untwisted is quite analogous to what is observed when, with no sustained longitudinal magnetising force, the current along a wire is reversed at different stages of untwisting.

There is one particular, however, in which the results of the present experiments differ from what might be expected if the accumulation of polarity was simply due to the magnetic effect of the current along the twisted wire.

First, it should be noted that the twist in a wire subjected only to the magnetising influence of a longitudinal field varied cyclically has no determinate effect in causing a change in the average polarity. Whatever be the polarity produced by a current passing along the twisted wire, we might naturally expect a cyclic field superposed thereon to give rise to a symmetrical variation of magnetic intensity about this acquired polarity as a mean. Consequently the difference of the average polarities for positive and negative currents should be equal to the range of polarity when the current is reversed in the twisted wire. As a fact, however, it is much greater. For instance, in the case given above for twist $+25'$ the range of polarity produced by reversing the current, the field being zero, was only 25; whereas the difference of polarities as given in the table is 42. Similarly, for twist $+37'{\cdot}5$, the range was 49, as compared with the difference 82·5; for the (second) twist $12'{\cdot}5$ the range was zero; and for twist $-37'{\cdot}5$ the range was 6, as compared with the difference 15·5.

The same peculiarity is shown to a more pronounced extent in nickel wire, of which I give here only one experiment. In spite of the greatest care in setting up the nickel wire, a change of average

polarity was in this case obtained at the first putting on of the current. The necessary fingering of the wire when clamping its ends seemed to give a slight twist, sufficient, however, to produce the effect spoken of. We may suppose the existence of the effect to prove that a twist did originally exist in the wire. I shall call for convenience this unknown initial twist x'. The results are these :—

For Nickel Wire of Diameter 0·9 *mm.*

Twist.	Current.	Field.	Range.	Polarity.
x'	0	±	273	+ 20·5
	+2·43	,,	240	+113
	−2·43	,,	238	− 46·5
$x'+12'{\cdot}5$	0	,,	287	+ 29·5
	+2·43	,,	237	− 66·5
	−2·43	,,	239	+102·5

In the first series (for twist x'), the range of polarity due to the reversal of the current was only 10, whereas the difference of the average polarities associated with positive and negative currents is as much as 159·5. It will be noticed that in passing from twist x' to twist $x'+10'$, the sign of the difference of polarities changes from positive to negative; while the amounts of the differences are nearly the same. This would indicate that x' had a value of approximately $-5'$; so that $x'+10$ becomes $+5'$. I am by no means satisfied, however, that (in nickel wire at any rate) there does not exist a measurable difference of polarities due to the current *only.* The great difficulty is to be sure that no twist exists in the wire; for it is quite evident that a very small twist is sufficient to produce a very large average polarity, when the wire is subjected to a steady circularly magnetising force in conjunction with a cyclically varying longitudinal field. If the effect is due only to the twist in the wire, we have here an extremely sensitive process for demonstrating the existence of a twist, especially in nickel wire.

The whole subject calls for more detailed discussion; and I am impelled to communicate these earlier results chiefly with the desire of correcting any false impressions that my preliminary note of last July might very easily give rise to. The facts there described are

accurate; but we see now that the more curious of them are comparatively easily explained as being due to an initial twist in the wire of a few minutes per unit length. This is true not only of the average polarity acquired, but also of the asymmetrical form of the curve with reference to the line of zero field. For, as may be seen by a study of Ewing's curves (*e.g.*, *Phil. Trans.*, plate lx. fig. 17, 1885), such an asymmetry exists in a cyclic curve taken about a mean value of field other than zero. Now here we have a finite mean value of longitudinal intensity supported by the current along the wire. If, in the curves shown in the preliminary note, we shift the upper narrow graph to the right and the lower one to the left so that their mean points have abscissæ equal to the longitudinal fields corresponding to their ordinates regarded as intensities, we shall see at once a sufficient reason for their asymmetrical form.

All that can be safely said regarding the effect of a current along an iron or nickel wire, upon the susceptibility of the same to a longitudinal field, is that the susceptibility is markedly diminished, and that the residual magnetism* falls off more quickly than the total reduced magnetism. In other words, a current along a wire diminishes the hysteresis (to use Ewing's word) relatively to a cyclically varying longitudinal field. The former conclusion agrees with the result obtained by Schultze (*Wied. Ann.*, xxiv., 1885) in his experiments on the reciprocal action of mutually perpendicular magnetisms. He experimented with iron and steel tubes, and the circular magnetisation was induced by currents altogether outside the iron. He does not seem to have discussed the properties of cyclic magnetic graphs, or even the ratio of the residual to the total induced longitudinal magnetism, with or without the circular magnetism. It is therefore impossible at present to say whether the diminished hysteresis here noted is due to the magnetic effect of the current in the wire, or, as is perhaps more probable, to the direct vibratory action of the current upon the molecules, thereby accelerating the breaking up of unstable molecular groupings.

* The experiments proving this are reserved, as not being quite completed.

On the Composition of some Deep-Sea Deposits from the Mediterranean. By J. Y. Buchanan, Esq., F.R.S.

(Read January 9, 1891.)

The muds, the analyses of which are reported in this paper, were collected in September 1879, during the laying of a cable between Marseilles and Algiers by the India Rubber, Gutta-Percha, and Telegraph Works Company, Limited, of Silvertown, the ship employed being the s.s. "Dacia." The numbers of the samples are those which were affixed to them on board ship. Nos. 31 to 43 are all from localities lying near the African Coast; Nos. 45 and 46 are from positions between the African Coast and the Balearic Bank. Nos. 64 and 65 are from the Balearic Bank, and Nos. 86 to 89 are from the Gulf of Lyons. The positions and depths are collected in Table I.

Table I.—*Giving the Position of the Ship where each Sample of Mud was Collected, and the Depth of Water there.*

No. of Sample.	Position.		Nature of Bottom.	Depth (fathoms).
	Latitude N.	Longitude E.		
	° ′	° ′		
31	36 57½	3 21	Soft mud.	1080
32	37 3	3 17	,,	1238
35	37 5	3 26	Clayey mud.	1258
36	37 9½	3 23	Mud.	1343
39	37 12	3 31	,,	1454
41	37 21	3 38	Soft mud.	1502
43	37 39	3 53	,,	1536
45	37 56	4 6	,,	1494
46	38 11	4 6	,,	1469
64	39 26	4 36	,,	782
65	39 35	4 40	,,	646
86	42 47	5 11½	Grey ooze.	780
87	42 53	5 18½	Clayey mud.	542
88	43 3	5 12	Mud and ooze.	530
89	43 1½	5 15	Mud.	265

The samples, as received, were in the condition in which they had been collected, having been transferred from the sounding-tube to the bottle without any form of preparation or drying. Some were therefore much wetter than others, and the diversity in their

condition in this respect is well shown in the percentage column of Table II. The actual state of the mud when put up in the sample bottle on board depends on so many fortuitous circumstances that no physical importance must be attached to the figures in this Table. In order to bring all the muds, as far as possible, into a similar condition, they were heated in the water-bath until they ceased to lose weight. It was necessary, therefore, to determine their weights, and they have accordingly been tabulated, and will give roughly an idea of the difference between a wet mud and a dry one.

TABLE II. *Preparation of Substance for Analysis.*—About half of the sample was placed in a tared porcelain basin and dried in the water-bath till it was in a fit form for handling. It was then weighed, and the loss of weight called water.

TABLE II.—*Preparation of Samples for Analysis, by Drying on the Water-Bath.*

No. of Sample.	Weight of Mud taken (grammes).	Weight of Mud dry (grammes).	Loss (grammes).	Per cent. of Loss.
	a	b	$c=a-b$	$d=100\frac{c}{a}$
31	28·4	19·3	9·1	32·04
32	23·8	18·15	5·65	23·71
35	22·9	15·3	7·6	33·18
36	23·0	16·4	6·6	28·69
39	14·7	11·7	3·0	20·40
41	26·3	16·9	9·4	35·73
43	29·5	20·0	9·5	32·20
45	25·1	20·2	4·9	19·52
46	19·9	16·1	3·8	19·09
64	24·6	19·7	4·9	19·91
65	38·5	27·3	11·2	29·09
86	25·4	19·2	6·2	24·41
87	25·4	20·7	4·7	18·50
88	29·5	19·8	9·7	33·25
89	22·0	16·9	5·1	23·18

The dried portion was broken up in an agate mortar, and preserved in a well-stoppered bottle. Sufficient quantities of each sample were thus prepared in a uniform manner, and the bottles in which they were preserved were carefully weighed and kept under a bell-jar. In this way any alteration in the substance is at once detected. If this precaution be not taken it is necessary, in dealing with substances which are more or less hygroscopic, to weigh out at

once all the portions of any one sample which will be required for the various determinations which are to be made, in order to be certain that a uniform material is used for each. This is attended with much inconvenience, which is obviated by preserving the sample in such a way that it will be unlikely to alter, and by keeping strict account of its weight, so as at once to detect any alteration which may occur.

TABLE III.—*Determination of Loss on Ignition, and of the Water and Carbonic Acid expelled thereby.*

No. of Sample.	Weight of Sample. Before Heating (grammes)	Weight of Sample. After Heating (grammes)	Loss (grammes)	Per cent. of Loss.	Weight of Water absorbed by $CaCl_2$ (grammes)	Per cent. of H_2O.	Weight of CO_2 absorbed by Soda-lime (grammes)	Per cent. of CO_2.	$i=f+h-d$
	a	b	$c=a-b$	$d=100\frac{c}{a}$	e	$f=100\frac{e}{a}$	g	$h=100\frac{g}{a}$	i
31	0·8180	0·7905	0·0275	3·36	0·0327	3·99	0·0086	1·05	1·68
32	0·7114	0·6873	0·0241	3·38	0·0200	2·81	0·0125	1·75	1·18
35	0·8978	0·8670	0·0308	3·38	0·0200	2·22	0·0240	2·67	1·51
36	0·7337	0·7068	0·0269	3·66	0·0242	3·29	0·0120	1·63	1·26
39	0·6940	0·6702	0·0238	3·42	0·0205	2·75	0·0007	0·10	− 0·57
41	1·0103	0·9724	0·0379	3·75	0·0322	3·18	0·0000	0·00	− 0·57
43	0·7640	0·7363	0·0277	3·62	0·0252	3·29	0·0041	0·53	0·20
45	0·4669	0·4539	0·0130	2·90	0·0168	3·59	0·0083	1·77	2·46
46	0·5529	0·5317	0·0212	3·83	0·0156	3·00	0·0088	1·59	0·76
64	0·5160	0·4598	0·0562	10·89	0·0451	8·74	0·0084	1·62	− 0·53
65	0·6972	0·6551	0·0421	6·03	0·0364	5·22	0·0090	1·29	0·48
86	0·7951	0·7500	0·0451	5·67	0·0301	5·68	0·0182	2·29	2·30
87	0·7999	0·7442	0·0557	6·96	0·0236	2·95	0·0300	3·75	− 0·26
88	0·6339	0·6071	0·0268	4·22	0·0207	3·26	0·0137	2·16	1·20
89	0·6010	0·5663	0·0347	5·77	0·0220	3·66	0·0065	1·08	− 1·03

Table III. *Determination of the Moisture, Carbonic Acid, and Total Loss.*—A quantity of the substance was weighed into a porcelain boat, placed in a combustion tube, and heated strongly in a current of air freed from moisture and carbonic acid by passing it through a tube filled with soda-lime and another filled with calcium chloride. The water was collected in a calcium chloride tube, and the carbonic acid in a soda-lime tube, and weighed. The boat was again weighed after the heating, and the difference in weight is called total loss. In every case the mud was of a reddish colour after heating. It will be observed that in all cases the loss of weight of the substance is different from the gain

of weight of the tubes; as a rule, it is decidedly less. In so complex a substance as a deep-sea mud it is impossible to account for this in detail; but organic matter, which is never absent from such muds, would, by its oxidation, increase the weight of the tubes at the expense of the air, while the oxidation of the fixed components, such as ferrous oxide, would have a like effect on the ignited mud. The figures, therefore, in the Table give a complex result, from which it is impossible to isolate the separate items. It is evident, from the general agreement of the figures, that the drying process (Table II.) has brought the various samples into a very fairly comparable condition.

TABLE IV. *Determination of the Carbonic Acid.*—A weighed quantity of the substance was placed in a flask and sulphuric acid added. The carbonic acid was collected in soda-lime tubes, being first dried by passing it through a U tube filled with pumice, moistened with concentrated sulphuric acid, and a tube filled with calcium chloride.

TABLE IV.—*Determination of Amount of Carbonic Acid.*

No. of Sample.	Weight of Sample taken (grammes).	Weight of CO_2 absorbed by 1st Soda-lime Tube (grammes).	Weight of CO_2 absorbed by 2nd Soda-lime Tube (grammes).	Total Weight of CO_2 (grammes).	Per cent. of CO_2.	Per cent. of $CaCO_3$.
	a	b	c	$d=b+c$	$e=100\frac{d}{a}$	f
31	1·7395	0·1396	...	0·1396	8·037	18·3
32	1·1346	0·0987	...	0·0987	8·10	18·4
35	1·5251	0·1268	0·001	0·1269	8·38	19·1
36	1·5970	0·1385	0·0006	0·1391	8·71	20·0
39	1·0160	0·1083	0·0017	0·1100	10·83	24·5
41	1·3468	0·1238	...	0·1238	9·19	21·0
43	1·5683	0·1600	...	0·1600	10·10	23·6
45	1·3200	0·1853	0·0002	0·1855	14·05	32·4
46	1·2864	0·2165	0·0009	0·2166	16·82	38·2
64	1·1379	0·2378	...	0·2378	20·90	47·1
65	1·8921	0·3129	...	0·3129	16·08	36·6
86	1·2456	0·1767	...	0·1767	14·19	32·5
87	1·4305	0·1909	...	0·1909	13·34	30·8
88	1·5087	0·2131	...	0·2131	14·12	32·5
89	1·4595	0·2024	...	0·2024	13·87	31·8

The flask was boiled to expel the gas, and a current of air, free from carbonic acid, was drawn through the apparatus to sweep out all the carbonic acid.

Near the African coast the amount of CO_2 varies between 8 and 10 per cent. It increases with distance from the land, being no doubt less masked by land debris. The maximum 20·97 of CO_2 (47·17 $CaCO_3$) is found on the Balearic Bank. The depth here was only 782 fathoms, and the land drainage is insignificant.

TABLE V. *Treatment with Hydrochloric Acid.*—(A.) A weighed quantity of the substance was placed in a porcelain basin and 100 c.c. of 20 per cent. hydrochloric acid added. The basin was placed on a water-bath and evaporated to dryness. It was then placed on an air-bath and heated so as to convert any soluble silica into the insoluble form. Then it was treated with hydrochloric acid and filtered. The precipitate was weighed, and called the "residue."

(B) The "residue" was fused with potassium sodium carbonate, and the silica determined in the usual way.

TABLE V.—*Determination of the Residue Insoluble in* 20 *per cent.* HCl, *and of the Total Silica.*

No. of Sample.	Weight of Sample taken (grammes).	Weight of Insoluble Residue (grammes).	Per cent. of Insoluble Residue.	Per cent. Soluble in Acid.	Weight of SiO_2 in Insoluble Residue (grammes).	Per cent. of SiO_2 in Sample.	Per cent. of SiO_2 in Insoluble Residue.
	a	b	$c=100\frac{b}{a}$	$100-c$	d	$e=100\frac{d}{a}$	$f=100\frac{d}{b}$
31	1·4796	0·8836	59·72	40·28	0·6456	43·64	73·06
32	1·8465	1·0952	59·31	40·69	0·8071	43·71	73·69
35	1·1713	0·4136	35·31	64·69	0·3213	27·43	78·08
36	0·8916	0·5896	66·13	33·87	0·3772	42·31	63·98
39	1·1890	0·6561	55·18	44·82	0·5276	44·37	80·41
41	1·7195	0·9598	55·81	44·19	0·7337	33·89	76·44
43	1·9403	1·0937	56·37	43·63	0·7219	32·41	66·00
45	1·3528	0·5774	42·68	57·32	0·4433	32·77	76·77
46	1·5053	0·5895	39·16	60·84	0·4715	31·32	79·98
64	1·3351	0·3755	28·13	71·87	0·2966	22·21	78·98
65	1·4602	0·4244	29·06	70·94	0·2160	14·79	50·89
86	1·7149	0·8339	48·63	51·37	0·5851	34·12	70·16
87	1·4539	0·6300	43·23	56·77	0·5349	36·79	85·10
88	1·5478	0·7622	49·25	50·75	0·5820	37·60	76·36
89	1·6682	0·8015	48·04	51·96	0·6300	37·68	78·60

TABLE VA. *Estimation of Iron and Alumina.*—The hydrochloric acid solution (the filtrate from the insoluble residue) was peroxidised with potassium chlorate, and ammonia was added till the precipitate locally formed was very slow in dissolving. Acetate of ammonium

was then added, and the mixture boiled and filtered, and the precipitate washed. The precipitate was dissolved in hydrochloric acid, and ferric hydrate precipitated with pure caustic potash in a platinum basin. It was then diluted and filtered, ignited and weighed. To the filtrate ammonium chloride was added, and the solution boiled till ammonia ceased to come off. The precipitate was filtered, ignited to Al_2O_3, and weighed.

In the Fe_2O_3 the variations are not great. The minimum, 3·45 per cent., is on the Balearic Bank, and the maximum, 6·64, in the deep water near the African shore. In this neighbourhood all the muds have large amounts of Fe_2O_3 and small amounts of Al_2O_3, except No. 35, where the amount of Fe_2O_3 is small and that of Al_2O_3 very large—in fact, the maximum (12·3 per cent.). It is remarkable that at No. 41 we find the maximum of Fe_2O_3 (6·64 per cent.), and the minimum of Al_2O_3 (1·3 per cent.). The deep water between Africa and the Balearic Islands covers muds comparatively rich both in Al_2O_3 and Fe_2O_3; on the Balearic Bank the amounts are small, and in the Gulf of Lyons moderate.

TABLE VA.—*Determination of* Fe_2O_3 *and* Al_2O_3 *in Hydrochloric Acid Solution of Table V.*

No. of Sample.	Weight of Sample taken (grammes).	Weight of Fe_2O_3 (grammes).	Per cent. of Fe_2O_3.	Weight of Al_2O_3 (grammes).	Per cent. of Al_2O_3.
	a	b	$c=100\frac{b}{a}$	d	$e=100\frac{d}{a}$
31	1·4796	0·0826	5·58	0·0203	1·37
32	1·8465	0·0991	5·37	0·0415	2·45
35	1·1713	0·0452	3·86	0·1441	12·30
36	1·5547	0·0956	6·17	0·0538	3·46
39	1·1890	0·0788	6·54	0·0460	3·87
41	1·7195	0·1060	6·64	0·0224	1·30
43	1·9403	0·1235	6·22	0·1864	9·60
45	1·3528	0·0720	4·23	0·1389	10·27
46	1·5053	0·0732	4·86	0·1645	10·93
64	1·1908	0·0505	4·24	0·0302	2·54
65	1·3671	0·0472	3·45	0·0292	2·04
86	1·7149	0·1073	6·26	0·0920	4·26
87	1·4539	0·0783	5·39	0·1212	8·34
88	1·7470	0·0763	4·37	0·0680	3·89
89	1·6682	0·0726	4·42	0·0765	4·58

TABLE VI. *Estimation of* FeO *and* Fe_2O_3.—A weighed quantity of the substance was placed in a 200 c.c. flask and the flask filled

Table VI.—*Determination of the State of Oxidation of the Iron extracted by Hydrochloric Acid.*

No. of Sample.	Weight of Sample taken (grammes).	Volume of $\frac{KMnO_4}{50}$ (c.c.) (mean of two estimations).	Equivalent Weight of FeO (grammes).	Per cent. of FeO.	Equivalent Weight of Fe_2O_3 (grammes).	Volume of $SnCl_2$(c.c.) (mean of two estimations).	Equivalent Weight of Fe_2O_3 (grammes).	Weight of Fe_2O_3 present in solution as Fe_2O_3 (grammes).	Per cent. of Fe_2O_3.	Per cent. of total Fe extracted (expressed as Fe_2O_3).	Per cent. of Fe_2O_3 (from Table V*a*.).	
	a	b	$c= 0072\,b$	$d=400\,\frac{c}{a}$	$e=\frac{10}{9}\,c$	f	g	$h=g-e$	$i=400\,\frac{h}{a}$	$k=400\,\frac{g}{a}$	l	$m=100\,\frac{k}{l}$
31	1·6273	1·3	0·00936	2·30	0·0104	2·30	0·01081	0·00041	0·11	2·66	5·58	47·67
32	1·8723	1·4	0·01008	2·15	0·0112	2·65	0·01245	0·00125	0·27	2·66	5·37	49·53
35	1·5134	1·2	0·00864	2·28	0·0096	2·20	0·01034	0·00074	0·19	2·73	3·86	70·73
36	1·9895	1·3	0·00936	1·88	0·0104	2·65	0 01245	0·00205	0·41	2·55	6·17	41·33
38	1·3194	0·8	0·00576	1·75	0·0064	2·12	0·00996	0·00356	1·08	3·02	8·72	34·63
39	1·5296	1·02	0·00734	1·92	0·00815	2·1	0·00987	0·00172	0·45	2·58	6·54	39·45
41	1·6770	0·9	0·00648	1·55	0·0072	1·82	0·00855	0·00135	0·32	2·04	6·64	30·72
43	1·5664	0·85	0·00612	1·56	0·0068	2·22	0·01043	0·00363	0·93	2·66	6·22	42·77
45	1·6763	0·8	0·00576	1·37	0·0064	1·75	0·00822	0·00172	0·36	1·96	4·23	46·34
46	1·6676	0·7	0·00504	1·21	0·0056	1·72	0·00808	0·00248	0·59	1·94	4·86	39·92
64	1·6684	0·52	0·00374	0·89	0·00415	1·86	0·00781	0·00366	0·88	1·87	4·24	44·10
65	2·0729	0·57	0·00410	0·79	0·00455	2·05	0·00861	0·00406	0·78	1·66	3·45	48·11
86	1·9550	1·05	0·00756	1·55	0·0084	2·95	0·01239	0·00399	0·82	2·53	6·26	40·41
87	1·9106	1·50	0·01080	2·26	0·0120	3·20	0·01344	0·00144	0·30	2·81	5·39	52·13
88	1·7496	1·20	0·00864	1·98	0·0096	2·57	0·01079	0·00119	0·27	2·46	4·37	56·29
89	1·8807	1·05	0·00756	1·61	0·0084	2·87	0·01205	0·00365	0·78	2·56	4·42	57·92

with carbonic acid gas. 20 c.c. of strong hydrochloric acid were also added, and the flask fitted with a cork pierced by a tube with an india-rubber valve. It was then heated on the water-bath for half-an-hour, filled up with boiling distilled water, corked, and allowed to cool. 50 c.c. were taken for analysis, and titrated first with potassium permanganate of $\frac{KMnO_4}{50}$ grammes per litre; and then with stannous chloride.

The stannous chloride used in the case of samples 31 to 46 was of such a strength that 1 c.c. = 0·0047 grms. Fe_2O_3, and in the case of samples 64 to 89, 1 c.c. = 0·0042 grms. Fe_2O_3. From the figures in Table VI. it will be seen that the bulk of the iron extracted in this way is in the ferrous state; while from column *m* the total amount of iron, expressed as Fe_2O_3, extracted in this way is only from 40 to 50 per cent. of the amount extracted by prolonged digestion.

TABLE VII.—*Summary, Percentage Composition of Muds.*

No.	SiO_2.	Balance Insoluble in HCl undetermined.	Total Insoluble Residue.	Fe_2O_3.	A $_2O_3$.	$CaCO_3$.	Loss on Ignition.	Balance Soluble in HCl undetermined.	Total Soluble in HCl.
31	43·64	16·08	59·72	5·58	1·37	18·3	3·36	11·67	40·28
32	43·71	15·60	59·31	5·37	2·45	18·4	3·38	11·09	40·69
35	27·43	7·88	35·31	3·86	12·30	19·1	3·38	26·05	64·69
36	42·31	23·82	66·13	6·17	3·46	20·0	3·66	0·58	33·87
39	44·37	11·45	55·18	6·54	3·87	24·5	3·42	6·49	44·82
41	33·89	21·92	55·81	6·64	1·30	21·0	3·75	11·50	44·19
43	32·41	23·96	56·37	6·22	9·60	23·6	3·62	0·59	43·63
45	32·77	9·91	42·68	4·23	10·27	32·4	2·90	7·52	57·32
46	31·32	7·84	39·16	4·86	10·93	38·2	3·83	3·02	60·84
64	22·21	5·92	28·13	4·24	2·54	47·1	10·89	7·10	71·87
65	14·79	14·27	29·06	3·45	2·04	36·6	6·03	22·82	70·94
86	34·12	14·51	48·63	6·26	4·26	32·5	5·67	2·68	51·37
87	36·79	5·44	43·23	5·39	8·34	30·8	6·96	5·28	56·77
88	37·60	11·65	49·25	4·37	3·89	32·5	4·22	5·77	50·75
89	37·68	10·36	48·04	4·42	4·58	31·8	5·77	5·39	51·96

In Table VII. the results of the foregoing Tables are collected so as to facilitate comparison of the general composition of the different muds.

On the Temperature of the Salt and Fresh Water Lochs of the West of Scotland, at Different Depths and Seasons, during the Years 1887 and 1888. By John Murray, LL.D., Ph.D.

(Read February 16, 1891.)

The temperature observations recorded in this communication were all taken from the yacht "Medusa," except those in Loch Morar, which were made from a small rowing-boat, but the same instruments and the same methods were used as in the other lochs.

All observations beneath the surface were made by means of Messrs Negretti & Zambra's reversing thermometer in the Scottish frame. The readings are published as they were observed, except that the instrumental correction is applied. The readings may, as a rule, be taken as exact to one-tenth of a degree when the sea was smooth, and when the temperature of water and air had a range less than six degrees. Experiments have shown that if a thermometer be reversed in water at 40°·0, and then brought to the temperature of 46°·0, it would change its indication slightly, and would read 40°·1. At first sight it would appear sufficient to subtract 0°·1 from the reading for each 6° of excess of air temperature over that registered by the instrument, and to add similarly in case the air temperature should be lower. This has not been done, because it was believed that, in summer at least, the cooling caused by evaporation from the wet instrument would reduce its temperature very considerably, and probably enough to make no correction necessary.

When it was possible to do so temperature was observed at very short intervals of depth, wherever there was a sudden change. For this reason, and in order to make it easy to compare conditions at any one depth, the somewhat diffuse plan of recording the readings was adopted.

Air temperature was observed by means of the sling thermometer.

The hour mentioned is in each case that at which the observation was commenced.

The weather being "bright" or "dull" means that the sky was not much clouded and the sun shining, or that it was overcast. The sea was always smooth, except where the contrary is noted. In

cases where the sea was "rough," the thermometer readings are liable to a little uncertainty, on account of the motion of the vessel.

With reference to the observations in the lochs of the Clyde sea-area, they were made during a series of trips at different seasons of the year, and the results of each trip are placed in chronological sequence as far as the geographical arrangements adopted permit.

The arrangement adopted for presenting these data is that of the natural districts into which the physical conformation divides the region under investigation. The districts are—(1) the *Estuary*, extending from Bowling to Greenock; (2) the *Gareloch;* (3) *Dunoon Basin*, which runs as a trough of about 40 fathoms in depth from the Dog Rock at the mouth of Loch Goil, through lower Loch Long, past Dunoon, and terminates a little to the north of the Cumbraes; (4) *Loch Long*, above the junction with Loch Goil; (5) *Loch Goil;* (6) *Holy Loch;* (7) *Kyles of Bute*, including under this name the shallow water between Ascog and Toward, as well as the Kyles proper, and Loch Ridun; (8) *Loch Strivan;* (9) *Arran Basin*, which includes the Firth of Clyde, from the south end of Arran to the Cumbraes, Inchmarnoch Water, Kilbrennan Sound as far south as Davaar Island, and lower Loch Fyne up to within one mile of Otter Ferry; (10) *Loch Fyne*, above Otter; (11) the *Plateau*, extending from Davaar Island and the Mull of Cantyre across the south end of Arran and Ailsa Craig to the Ayrshire coast; and (12) the *Channel* beyond this plateau.

The observations are arranged under each of the twelve natural districts, as far as possible in regular succession for each trip, from one end of the district to the other. As a rule, observations were made always in the same position during each trip, and it has been considered sufficient to designate these positions briefly in the record of temperature. The following statement will serve to fix them with precision:—

ESTUARY.—Observations made in mid-channel when the places specified were just abeam.

GARELOCH.—*Helensburgh*—Observations made a few hundred yards off the pier.

Row (I.)—In about 12 fathoms, just seaward of Row Point.

Row (II.)—In about 25 fathoms, $\frac{1}{2}$ mile above the point, and in the centre of the loch.

Shandon—In 21 fathoms, centre of the loch, opposite Balernock Pier.

Head—In 10 fathoms, at the buoys.

DUNOON BASIN.—*Dog Rock*—40 to 50 fathoms, ½ mile S. by W. of Dog Rock.

Coulport—42 fathoms, midway between Coulport and Ardentinny.

Blairmore—30 fathoms, mid-loch, opposite Blairmore.

Strone Point—30 fathoms, ½ mile E. of the point.

Gantock.—50 fathoms, ½ mile S. of Gantock Beacon, off Dunoon.

Cloch—50 fathoms, ½ mile N.W. of Cloch Light.

Wemyss.—40 fathoms, ¼ mile N.W. of Wemyss Point.

Knock Hill—40 fathoms, ¾ mile off shore W. of Knock Hill.

LOCH LONG.—Centre of the loch, opposite the places named. At *Arrochar*, one station in 15 fathoms, has the "Cobbler" bearing N.N.W.; the other, 9 fathoms, is just off the pier.

LOCH GOIL.—*Mouth*—Midway between Corryn and Bird Point.

Stuckbeg—40 fathoms, middle of loch, opposite Stuckbeg.

Head—27 fathoms, off Lochgoilhead Pier.

HOLY LOCH.—*Mouth*—16 fathoms, midway between Strone Point and Hunter's Quay.

Head—10 fathoms, between Sandbank and Kilmun.

KYLES OF BUTE.—*Ascog*—23 fathoms, ½ mile off shore, opposite Ascog.

Bogany—27 fathoms, ½ mile N.E. of Bogany Point.

Toward—7 fathoms, between Toward Point and Toward Bank Buoy.

Rothesay—20 fathoms, mouth of Rothesay Bay.

Strone Cotes—20 fathoms, mid-channel, opposite Strone Cotes.

Angle—25 fathoms, mouth of Loch Ridun, between Burnt Islands and Caladh Island.

Ormidale, Loch Ridun—12 fathoms, off Ormidale Pier.

Achanlochan—15 fathoms, in West Kyles.

LOCH STRIVAN.—*Mouth*—33 fathoms, midway between Ardine Point and Strone Point.

Clapochlar—35 fathoms, mid-channel, off Clapochlar Point.

Head—13 fathoms, ½ mile from head of loch.

ARRAN BASIN.—*Largybeg*—60 fathoms, 2 miles S.E. by E. of Largybeg Point, Arran.

Brodick—90 fathoms, Goatfell bearing W.N.W., Garroch Head N.N.E.; 5½ miles from Brodick.

Garroch Head—60 fathoms, midway between Garroch Head and Little Cumbrae Light.

Uillean—60 fathoms, midway between Uillean Point and Tan Buoy.

Imacher—75 fathoms, midway between Imacher Point and Carradale, Kilbrennan Sound.

Areverga—70 fathoms, 1 mile W. of Areverga Point, Kilbrennan Sound.

Inchmarnoch—85 fathoms, midway between Inchmarnoch and Cock of Arran.

Ardlamont—30 fathoms, midway between Ardlamont Point and Etterick Bay, Kyles of Bute.

Skate Island—104 fathoms, 1 mile W. of Skate Island, Loch Fyne.

Otter (*I.*)—30 fathoms, 1 mile W. of Otter Beacon, Loch Fyne.

LOCH FYNE.—*Otter* (*II.*), *Otter* (*III.*)—1 and 2 miles respectively N.E. of Otter Beacon. The other stations in Loch Fyne are in mid-channel, opposite Gortan's Point, Furnace Quarry, Pennimore, Strachur, Inveraray, Dunderave Castle, and Cuill.

PLATEAU.—*Sanda*—A few miles to the E. of Sanda Island.

Pladda—1 mile S. of Pladda Island.

Rhuad Point—½ mile off shore at Rhuad Point.

Ailsa—1 mile N. of Ailsa Craig.

CHANNEL.—*Mull of Cantyre*—70 fathoms, 2 miles S. of Mull of Cantyre Light.

Deas Point—35 fathoms, ½ mile, 50 fathoms, 1 mile, S. of Deas Point.

Maidens—6½ miles N.E. of Maidens Light.

Corsewell—9 miles N.W. of Corsewell Light.

N.B.—All the bearings given above, and the direction of wind in all the observations, are magnetic.

The observations in the lochs to the north of the Clyde sea-area are for the most part limited to the spring and summer months, but are very interesting for the purposes of comparison, as well as valuable in themselves.

Many of the observations recorded in the following Tables were taken with the special object of detecting the effect of winds on the distribution of temperature in the waters of the lochs. It was

found that when the wind was off-shore, or down from the heads of the lochs, cold water was brought to the surface in summer; in winter, on the other hand, warm water was brought to the surface from the deeper portions of the lochs. It will be seen that when the sea-lochs have a depth of 80 or 100 fathoms, the warmest water is found at the bottom in the months of December and January, and the coldest water in June and July.

A large number of temperature observations taken in the western lochs of Scotland from the "Medusa" in previous years, have been published and partially discussed in the Journal of the Scottish Meteorological Society[1] and the Scottish Geographical Magazine.[2] A more detailed discussion of the observations is now in progress, and will shortly be presented to this Society by Dr H. R. Mill.

The observations were for the most part taken by myself and Captain Alexander Turbyne of the "Medusa," occasionally assisted by gentlemen who have taken part in the work of the Scottish Marine Station. The results were copied from the observation books and prepared for press by Dr Mill and Mr James Chumley.

[1] *Jour. Scot. Met. Soc.*, 3rd ser., Nos. iii. and iv., 1886, 1887.

[2] *Scot. Geogr. Mag.*, vol. iv. pp. 345–365, 1888.

1887.	LOCH NESS.					LOCH OICH.	
Date	April 26	April 26	April 26	April 26	April 26	April 26	April 26
Position	Off Aberiachan Pier	Off Temple, about 2 miles N.E. of Urquhart Castle	Off Castle Urquhart	About 1 mile from end of Loch	South of Canal entrance, Fort Augustus, foot of Loch	North east end	South east end
Hour	9.33	10.48	11.20	14.45	15.15	18.5	18.40
Wind	E., 2	N.E., 3	N.E., 4 or 5	W., 3 or 4	S.W., 3	S.W., 0·5	S.W., 2
Weather & Sea	Mist & snow, roughish	Mist, snow, and sleet, rough	Mist, rain, and snow, rough	Snowstorms, rough	rain and snow, rough	Cloud, and occasional sunshine, roughish	Fine, sunshine, smooth
Depth	61	119	120	85	42	12½	23
Temp. of Air	36·9 (wet)	37·0	36·5	38·0 (wet)	38·0	39·8	38·5
Fathoms							
0	42·0	42·1	41·8	41·5	41·8	44·0	44·2
1	42·2	...	...	...	...	44·2*	...
2	42·3	42·2	...	41·5	41·7	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	42·3	42·2	...	41·5	41·7	...	44·2
6	...	...	...	...	...	44·2*	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	42·2	42·1	42·0	41·5	41·5	...	44·2
12	...	...	...	...	...	44·2‡	44·2
14	...	...	...	...	41·5†		...
16	...	...	...	...	...	...	44 2†
18	...	...	...	...	...	...	...
20	42·2	42·1	...	41·5	41·5	...	...
22	. .	...	...	...	...	...	44·2
24	...	...	...	...	...	...	
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	42·2	42·1	42·0	41·5	41·4†	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	41·4	...	...
38	...	...	...	...	...	...	...
40	42·2	42·1	...	41·5	41·4†	...	...
42	...	...	...	...		...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	42·3	42·1	42·0	41·5	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	42·2	42·1	...	41·6	...	...	...
62		...	...	...	...	...	...
64	...	...	...	41·5	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	41·5	...	...	...
76	...	...	...	...	...	...	...
78	...	41·9	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	41·8†	41·5	...	...	...
86	...	...	...	The wind was strong N.E. at upper end of Loch, at Foyers it changed to strong S.W., the opposite direction from the forenoon.	...	...	...
88	...	...	...		...	...	...
90	...	...	...		...	...	...
92	...	...	...		...	...	...
94	...	...	...		...	...	..
96	...	...	...		...	...	...
98	...	41·7	...		...	...	...
100	...	...	41·6		...	...	...
112	...	...	...		...	...	...
118	...	41·5	...		...	...	...
121	...	...	41·5		...	...	...

* Observation made ½ fathom deeper than indicated. † Observation made 1 fathom deeper than indicated.
‡ Observation made ½ fathom less deep than indicated

1887.	LOCH MORAR.						
Date . .	April 29	April 29	April 29	April 29	April 29	April 29	April 29
Position .	S. of Islands, N. of Rudha Garbh, near centre of W. basin	¾ mile E. of Islands, centre of Loch	Between Inbhir Beag and Lettermore	½ mile W. of line between Brinacory Island and Allenhara	About 1½ miles E. of last position	Little W. of line between Swordland & Mouth of River Moble	1 mile East of Tarbet, centre of Loch
Hour . .	8.45	9.10	9.45	...	10.55	11.30	12.30
Wind . .	E., 2	E., 3	E., 3	E., 2	E., 3	E., 3	E., 3
Weather & Sea . .	Sunshine, roughish	Sunshine, cloud, rough	Sunshine, cloud, rough	Sunshine, roughish	Sunshine, rough	Sunshine, rough	Cloudy, rough
Depth .	33	82	118	111	147	165	157
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	43·1	42·9	43·1	...	...	...	43·4
1	...	...	...	43·4	43·8	43·1	43·5
2	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	42·9	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	42·6	...	...	...	...	...
12	...	...	...	...	...	...	...
14	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	42·3	...	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	42·3	...	...	...	...	...
32	42·2†	...	...	...	...	...	...
34		...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	42·0†
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	42·1	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	42·1	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	42·1	...	...	...	...
80	...	...	...	...	...	...	...
82	...	42·0	...	...	...	...	...
84	...		...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
104	...	...	...	...	42·0	...	...
110	...	...	...	42·0	...	...	...
112	...	...	...		...	...	...
118	...	...	42·0	...	...	...	...
125	...	...		...	...	42 0	...
147	...	...	...	...	42·0	...	...
157	...	...	...	...		...	42·0
165	...	...	...	...	...	42·0	

† Observation made 1 fathom deeper than indicated.

1887.	LOCH MORAR.		LOCH SHIEL.	LOCH SUNART.		SOUND OF MULL.	
Date . .	April 29	April 29	...	May 1	May 1	May 1	May 1
Position .	Within mile of E. end of Loch, Oban, and Kinlochmorar	On section bet. Tarbet Point and Cruch Dhubh an Ruidhe Fheâne	Off Ben Rosipol	1 mile East of Mor Island	N.E. Charna Island	Off Auliston Point, East of Big Stirk	Between Fishnish Bay and Savory River
Hour . .	14.50	16.30	...	10.50	...	13.45	15.30
Wind . .	E., 2	E., 1	...	E., 0·5	W., 3	W., 2	W., 2
Weather & Sea . .	Cloudy, ripply	Sunshine, smooth	...	Cloudy, smooth	Showery, overcast, smooth, roughish	Overcast, roughish	Overcast, fine, smooth
Depth .	57	170	31	42	64	65	58
Temp. of Air	...	...	...	46·2	...	...	46·4
Fathoms							
0	43·9	43·5	43·9	46·2	46·6	45·8	45·9
1	...	43·3	...	...	...	45·8	45·8
2	43·7	...	44·0	...	...	...	...
3	43·7	43·1	...	...	...	...	...
4	...	...	...	...	...	...	...
5	43·5	43·1	43·3	46·1	45·9	45·7	45·5
6	...	...	...	...	...	...	...
7	43·3	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	43·0	43·0	43·0	45·6	45·7	45·8	45·5
12	...	...	...	...	...	...	...
14	42·6†	...	...	...	...	...	...
16	...	...	...	...	...	...	45·3†
18	...	...	...	...	...	...	...
20	42·3	43·0	43·0	45·5†	...	...	...
22	...	...	...	...	45·7†	...	...
24	...	...	...	...	...	46·0	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	42·2	42·8	43·0†	45·3†	...	...	...
32	...	...		...	...	...	...
34	...	...	...	...	...	...	...
36	42·0†	...	...	...	...	...	45·5†
38	...	...	...	...	...	...	...
40	...	...	...	45·2†	...	...	...
42	...	...	...		45·7†	...	...
44	...	...	...	...	...	46·1	...
46	42·1†	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	42·1†	...	...	...	...	...	45·6†
58		...	...	...	...	...	
60	...	...	...	...	...	...	...
62	...	...	...	...	45·7†	...	...
64	...	...	...	...		46·2	...
66	...	...	...	...	...		...
68	...	...	...	...	...	...	...
70	...	42·1	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
112	...	...	...	...	...	...	...
170	...	42·0	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	SOUND OF MULL.	FIRTH OF LORNE.				FIRTH OF LORNE.	
Date . .	May 1	May 1	May 2	May 2	May 2	May 3	May 3
Position .	100 fathoms patch bet. Lismore Light and Morven Coast	Midway bet. Loch Don, Mull, and Kerrera	100 fathoms patch bet. Sheep Island and Mull	Mouth of Loch Buy, Mull	Loch Buy, off Island at head of Loch	Halfway bet. Light end off Lismore and Dunolly Castle	Oban Bay
Hour . .	...	17.45	11.0	12.55	13.45	17.10	18.20
Wind . .	Calm	S.W., 2	S.W., 1	Calm	S.W., 0·5	N.E., 2	Calm.
Weather & Sea . .	Overcast, fine, smooth	Fine, cloudy, roughish	Overcast, smooth, long swell	Sunshine, hazy, smooth, swell	Sunshine, smooth with swell	Cloudy, roughish	Fine, smooth
Depth .	100	96	96	53	12	...	22
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	45·6	45·5	45·8	...	47·3	47·3	47·1
1	...	45·3	45·6	...	46·2	46·9	46·6
2	...	...	45·3	45·9	...	...	...
3	...	...	45·3	...	...	46·0	46·1
4	...	...	...	...	...	...	...
5	45·5	45·3	45·2	45·8	...	45·4	...
6	...	...	...	...	45·9	...	46·0
7	...	...	45·2	...	...	...	...
8	...	...	45·2	...	...	...	...
9	...	45·3	...	...	...	45·0	...
10	45·3	...	45·3	45·5	45·8†	...	45·9†
12	...	...	...	...		...	...
14	...	...	45·4†	45·3†	...	45·2	...
16	...	...	45·4	...	...	...	45·6
18	45·1†	...	...	...	...	45·2†	...
20	...	...	45·4	...	...		45·6†
22	...	...	...	...	...	...	...
24	...	...	...	45·3†	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	45·3	45·4	...	...	...
32	...	...	...	45·4	...	...	...
34	...	45·1†	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	45·3	...	...	...	...
42	...	...	...	45·6	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	45·7	...	...	...
54	...	45·2†	45·2†		...	...	...
56	...	...	...	...	...	...	...
58	45·1†	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	45·2†	45·3†	...	...	...	...
96	...	...	...	...	...	...	...
98	45·2†	...	...	...	...	...	...
100		...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.							
Date	May 4	May 4	May 4	May 4			
Position	Bet. W. ends of Scabra & the Isles of the Sea	On Tarbert Bank off Loch Tarbert, N. end of Sound of Islay	Sound of Islay, a little South of Port Askaig	E. by S. of Otter Rock, bet. Islay and Cantyre			
Hour	9.10	12.0	13.50	16.15			
Wind	Calm	S., 0 to 1	S.W., 2	E., 3			
Weather & Sea	Sunshine, clouds, smooth, long swell	Sunshine, smooth, long swell	Cloudy, sunshine, smooth or roughish	Sunshine and cloud, rough			
Depth	138	8	31½	67			
Temp. of Air	...	...	...	...			
Fathoms							
0	46·2	47·0	46·2	47·5	...	...	...
1	45·8	...	45·9	...	...	...	...
2	45·8	46·8	46·0	46·4	...	...	...
3	45·7	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	45·7	...	46·0	46·0	...	...	...
6	...	...	...	...	...	...	...
7	...	46·5	...	...	...	...	...
8	...		...	...	...	...	...
9	45·5	...	45·9	...	...	...	...
10	...	...	...	45·6	...	...	...
12	...	...	...	...	...	...	...
14	45·5†	...	...	45·5†	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	45·5	...	46·0*	45·5	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	45·3	...	...	...
28	...	...	...	...	...	...	...
30	45·4	...	46·0*	...	...	...	...
32	...	...		...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	45·5	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	45·2	...	...	...
48	...	...	...	...	...	...	...
50	45·5	...	...	45·2	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	45·6	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	45·2	...	...	...
68	...	...	...		...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	45·5†	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	45·6	...	...	...	...	...	...
117	45·5	...	...	...	...	...	...
137	45·6	...	...	...	...	...	...

* Observation made ½ fathom deeper than indicated. † Observation made 1 fathom deeper than indicated.

1887.	FIRTH OF LORNE.			LOCH ETIVE.	MULL SOUND.	LOCH LINNHE.	
Date . .	August 18	August 18	August 19	August 20	August 22	August 26	August 26
Position . .	Off Mull	Off Mull further out	Off Sheep Islands	Off Mouth	Between Lismore & Morven Shore	Off Eil baile Ghobbain & Rudha na h'earba	Corran Ferry
Hour . .	19.20	19.40	12.15	...	14.45	11.55	13.0
Wind . .	N.W., 3	...	Calm	...	S.W., 4	S.W., 2	S.E., 2
Weather & Sea . .	Sunshine, rough, swell	...	Sunshine, cloud, smooth	Cloudy	Rain, mist, rough	Cloud, hazy, sunshine, smooth	Hazy, smooth
Depth .	22	49	106	18	107	54	17
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	..	55·3	55·8	...	55·5	56·0	...
1	55·5	...	55·7	...	...	...	...
2	...	...	55·6	...	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	...	...	55·4	...	55·7	55·7	...
6	...	...	...	...	...	...	55·0
7	...	...	...	55·5	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	55·6†	55·2	55·4	...	55·7	55·4	55·2†
12	...	...	...	55·6	...	...	...
14	...	...	55·4†	...	...	55·4†	...
16	...	...	...	55·3†	...	...	55·1
18	...	...	...		...	...	
20	55·5†	55·2	55·4	...	55·6	55·6	...
22		...	...	...	...	...	...
24	...	55·3	55·5†	...	...	...	...
26	...	...	..	...	...	...	...
28	...	55·3	...	...	...	...	...
30	...	...	55·5	...	55·7	55·2	...
32	...	...	...	...	...	55·1†	...
34	...	...	55·4†	...	...	...	...
36	...	...	...	...	...	...	...
38	...	55·3	...	...	..	...	...
40	...	...	55·4	...	...	...	...
42	...	...	...	...	...	54·9†	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	55·3	...	...	...	...	..
50	...		55·5	...	55·7	...	...
52	...	...	...	...	...	54·7†	...
54	...	...	...	...	...		...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	55·5†	...	...	...	...
66	...	...	...	...	55·7	...	...
68	...	...	..	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	..	...
82	...	...	...	...	...	...	...
84	...	...	55·6†	...	...	..	...
86	...	...	...	...	55·9	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	..	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	55·5†	...	...	...	...
102	..	...		...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	55·4	...	...
108	...	...	...	...		...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH ABER.			LOCH LEVEN.		LOCH HOURN.	
Date	August 26	August 27	August 27	August 27	August 29	August 29	August 29
Position	Off Inver Seadle Bay	Off Fort William	Off Inver Seadle Bay	Off Ballachulish Slate Quarries	Centre Sound of Sleat, off Isle Oransay	Mouth	Mouth
Hour	13.50	9.30	10.40	12.10	10.0	10.40	10.55
Wind	S.W., 2	S.W., 1	S.W., 2	S.S.W., 2	S.E., 0·5	W., 1	W., 1
Weather & Sea	Hazy, cloudy, smooth	Sunshine, smooth	Sunshine, smooth	Cloud and sunshine, smooth	Sunshine, smooth	Cloud, sunshine, smooth	Cloudy, smooth
Depth	80	37	down to 50	29	49	66	95
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	56·3	57·8	56·8	57·0	57·3	...	57·4
1	...	56·1	...	...	...	...	...
2	56·0	...	55·5	56·1	...	...	57·2
3	55·1	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	55·2	55·0	56·0	55·7	56·5	...	57·0
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	55·1	...	...	...	...	..	...
9	...	...	...	...	...	...	...
10	55·2	55·0	...	55·7	56·0	...	56·5
12	...	...	...	...	...	...	...
14	55·2†	54·7†	...	55·3	55·8†	...	55·4†
16	...	54·8†	...	...	...	...	...
18	...	...	...	55·4	...	...	...
20	55·1	54·6†	...	...	55·1	...	55·4
22	...	...	...	55·4†	...	...	...
24	55·1†	...	...	...	55·4†	...	55·3†
26	...	54·6†	...	...	...	...	...
28	...	...	...	55·3	55·6	...	...
30	55·0	...	54·9	...	...	...	55·3
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	55·2†
36	...	54·3†	...	...	...	...	...
38	...	...	...	...	55·3	...	...
40	55·2	...	55·2	...	...	...	54·0
42	...	...	...	...	...	...	...
44	...	...	...	...	...	53·7†	...
46	...	...	...	...	...	...	...
48	...	...	...	...	54·0	...	...
50	55·1	...	55·1	...	...	...	53·3†
52	...	...	...	...	...	...	...
54	...	...	...	...	...	52·0†	...
56	...	...	...	...	...	...	...
58	55·0†	...	...	...	...	...	...
60	...	...	...	...	...	...	50·9
62	...	...	...	...	...	...	...
64	...	...	...	...	...	50·1†	...
66	...	...	...	...	...	...	...
68	55·2†	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	49·7
76	...	...	...	...	...	...	...
78	55·1†	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	49·7
86	..	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	49·4
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH HOURN.			LOCH CARRON.			OUTER LOCH CARRON
Date	August 29	August 29	August 29	August 30	August 30	August 30	August 31
Position	Off Coir Island	Bet. Cnoe of Kyle and E. Mousker	Head, off Skiary	Narrows off Port Hulin, West of Strome Ferry	Centre	Head, off Long Island	Bet. Ru Duard and Ru Nauag
Hour	12.30	13.0	13.25	11.35	12.10	13.0	15.15
Wind	N., 3	W.S.W., 3	W.S.W., 3	N.W., 4	W.N.W., 5	W., 5	W., 0
Weather & Sea	Showery, sunshine, smooth	Sunshine, cloud, smooth	Cloudy, sunshine, smooth	Rain, squally, roughish	Squally, roughish	Squally, rain, roughish	Sunshine, smooth
Depth	31	15	11	11	56	22	66
Temp. of Air	...	...	...	...	...	...	64·8
Fathoms							
0	57·3	...	56·5	55·7	55·9	56·9	58·9
1	...	...	...	55·6	...	...	...
2	...	...	...	...	...	...	56·9
3	...	...	...	55·7	55·8	56·3	...
4	...	56·2	...	...	...	...	...
5	56·3	...	56·2	55·6	55·4	...	55·3
6	...	...	...	...	...	...	...
7	...	...	...	...	55·5	55·9	54·6
8	...	...	...	55·5	...	...	...
9	...	56·3	...	...	...	...	...
10	56·0	...	55·9	55·4	55·3	55 3†	54·5
12	...	...			...	...	...
14	55·8†	56·1	...	...	55·2†	...	53·9†
16	...		...	...	...	55·4	...
18	...	...	...	...	...	...	...
20	55 6	...	...	...	54·9	55·3†	53·7
22	...	...	...	...	...		...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	54·1	...	...	...	54·5	...	53·3
32		...	...	...	...	...	...
34	...	...	...	...	54·4†	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	53·0
42	...	...	...	...	...	...	...
44	...	...	...	...	54·4†	...	52·9†
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	54·2†	...	52·9†
56	...	...	...	...		...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	52·6†
66	...	...	...	...	...	...	
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH DUICH.			LOCH ALSH.	INNER SOUND.	LOCH MORAR (Fresh Water).	
Date	August 31	Sept. 1	Sept. 1	Sept. 1	Sept. 1	Sept. 3	Sept. 3
Position	Off Kintail	Head (Anchorage)	Off Mouth of Loch Long	Off Mouth of Kyle Rhea	Bet. Croulin, Mor and Longa Island	Off Tarbet, nearly half way across	Off Tarbet
Hour	18.0	8.30	10.5	10.55	15.0	9·5	...
Wind	N., 2	N.N.W., 1	S.W., 2	S.S.W., 3	W., 3	W., 3	...
Weather & Sea	Overcast, smooth	Dull, showery, smooth	Rain (heavy), smooth	Rain, cloudy, smooth to roughish	Sunshine, roughish	Cloudy, showers, roughish	...
Depth	60	7	11	39	127 (no bottom)	162	...
Temp. of Air	60·5	...	...	56·0	61·2	...	...
Fathoms							
0	59·0	57·0	56·9	56·0	56·9	57·8	...
1	...	...	...	...	...	...	...
2	56·2	55·2	...	...	56·9	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	55·5	...	55·9	56·0	56·1	57·9	...
6	...	55·0	...	...	...	...	...
7	54·9		...	...	...	...	...
8	...	...	...	...	...	58·0	...
9	...	...	...	...	...	...	...
10	54·9	...	55·5	56·0	54·4	57·6	57·8
12	...	...		...	...	57·6†	...
14	54·9†	...	...	...	...	51·0†	52·0†
16	...	...	...	...	...	...	...
18	...	...	...	55·9	...	52·1	...
20	54·7	...	...	...	54·0	46·8	47·0
22	...	...	...	...	...	...	...
24	...	...	...	...	...	54·3†	46·1
26	...	...	...	...	...	...	45·6‖
28	...	...	...	55·8	...	...	44·8‖
30	54·2	...	...	...	...	44·0	44·2
32	...	...	...	...	...	...	
34	53·2†	...	...	...	...	44·4†	
36	...	...	...	...	...	...	
38	52·7†	...	...	55·7	...	...	
40	...	...	...		53·1	43·6	
42	...	...	...	...	...	...	
44	...	...	...	...	...	...	
46	...	...	...	...	...	...	
48	52·2†	...	...	...	...	...	
50	...	...	...	...	52·7	42·7	
52	...	...	...	...	...	...	
54	...	...	...	...	...	...	
56	...	...	...	...	...	...	
58	52·0†	...	...	...	...	...	
60		...	...	...	...	42·6	
62	...	...	...	...	...	...	
64	...	...	...	...	...	...	
66	...	...	...	...	...	...	
68	...	...	...	...	...	...	
70	...	...	...	...	51·7	42·3	
72	...	...	...	...	...	...	
74	...	...	...	...	...	...	
76	...	...	...	...	...	...	
78	...	...	...	...	...	...	
80	...	...	...	...	...	42·3	
82	...	...	...	...	...	...	
84	...	...	...	...	...	...	
86	...	...	...	...	...	...	
90	...	...	...	...	51·0	42·4	
100	...	...	...	...	...	42·3	
106	...	...	...	...	50·7	...	
110	...	...	...	...	...	42·3	
116	...	...	...	...	50·7	...	
120	...	...	...	...	...	42·5	
126	...	...	...	...	50·6	...	
130	...	...	...	...		42·3	
141	...	...	...	...	...	42·2	
151	...	...	...	...	...	42·4	
161	...	...	...	...	...	42·1	

Though a fresh-water loch, Loch Morar is the deepest of all the lochs of the west of Scotland, the greatest depth being 180 fathoms.

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	UPPER LOCH NEVIS.		OUTER LOCH NEVIS.				UPPER LOCH SUNART.
Date	Sept. 3	Sept. 3	Sept. 3	Sept. 4	Sept. 4	Sept. 4	Sept. 5
Position	Head	Centre		Bet. North of Eigg and River Moror	Bet. Muke and Ardnamurchan Light	Off Ardnamurchan Point	Off Ru Strone na Saoibhaidh
Hour	15.45	16.0	18.45	10.5	13.	15.50	9.0
Wind	W., 1	W., 3	W.N.W., 2	N., 2	E.N.E., 3	E.N.E., 3	S.E., 2
Weather & Sea	Sunshine, smooth	Sunshine & cloud, rough to smooth	Clear, sunshine, smooth	Overcast, roughish	Overcast, roughish swell	Sunshine, cloud, roughish swell	Cloudy, smooth
Depth	11	56	56	54	113	43	51
Temp. of Air	...	59·2	...	57·0	57·2 ; 57·5	57·8	...
Fathoms							
0	56·9	56·7	57·0	57·2	57·6	57·6	56·7
1	...	...	...	...	...	...	...
2	...	...	...	57·1	...	...	57·2
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	56·1	56·2	56·8	57·1	57·4	57·4	57·2
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	56·0	55·9	56·6	57·2	57·3	57·3	57·1
12		...	...	...	...	...	...
14	...	...	56·2†	...	57·4†	...	57·1†
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	55·9	55·9	57·1	57·4	...	57·0
22	...	...	...	...	...	57·3	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	55·2	54·8	56·5	57·3	...	56·8
32	...	...	...	56·5†	...	57·2	...
34	...	53·8†	53·8†	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	51·9	...	...	57·3	...	56·7
42	...	...	...	56·1†	...	57·1	...
44	...	50·0†	53·0†	...	...		...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	56·6
52	...	...	...	55·9†	...	...	
54	...	49·3†	52·7†		...	...	...
56	...			...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	57·3	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	57·2	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	57·1	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	57·2	...	...
104	...	...	...	....	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...
112	...	...	...	...	57·2	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH SUNART.	SOUND OF MULL.		LOCH EIL.		CALEDONIAN CANAL (Fresh Water).	LOCH LOCHY (Fresh Water).
Date	Sept. 5	Sept. 5	Sept. 5	Sept. 5	Sept. 6	Sept. 7	Sept. 7
Position	N.E. Charna Island	Off Runan Aulistan	Off Fishnish Bay	Between Lismore and Morven Shore	2 miles from inner end of Narrows	Garelochy Loch, end nearest Bannavie	Off Auchna-carry (South end)
Hour	11.15	12.20	15.5	18.5	17.5	10.30	12.45
Wind	E.S.E., 2	S.S.E., 3	S.E., 2	S.E., 2	E., 4	N.E., 1	N.E., 2
Weather & Sea	Cloud, sunshine, smooth	Overcast, roughish	Cloudy, sunshine, smooth	Overcast, rain, rough	Rain, roughish	Sunshine, clouds, smooth	Fine, sunshine, smooth to roughish
Depth	59	46	59	110	35	3	37
Temp. of Air	58·4	...	59·8	56·1 (wet)	53·0 (wet)	...	53·0
Fathoms							
0	57·4	57·1	56·8	56·5	55·5	55·0	56·5
1	...	...	...	...	...	...	...
2	...	...	...	...	...	55·0	56·2
3	...	...	...	...	...		...
4	...	...	...	...	...	...	...
5	57·2	...	56·7	...	55·2	...	56·0
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	56·1
9	...	...	...	...	...	...	...
10	57·0	57·1	56·7	...	55·2	...	56·1
12	...	...	...	...	...	...	...
14	57·0†	...	56·7†	...	55·2	...	56·0†
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	53·8
20	57·1	57·1	56·8	56·5	...	...	47·1
22	...	...	...	...	...	...	...
24	...	57·1†	...	...	55·3	...	45·7
26	...	...	...	...	...	...	45·1
28	...	...	...	...	...	...	...
30	57·0	...	56·8	...	...	...	45·0†
32	...	...	...	...	...	...	...
34	...	57·2†	...	...	55·2	...	...
36	...	...	...	...		...	44·0
38	56·9	...	56·9	...	...	...	
40	...	...	...	56·5	...	...	...
42	...	...	...	...	...	...	...
44	...	57·3†	...	...	...	...	...
46	...		...	...	...	...	...
48	57·0	...	57·0	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	56·8	...	57·0	...	...	...	...
60		...		...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	56·6†	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	56·7†	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
108	...	...	...	56·5†	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH LOCHY (Fresh Water).		LOCH OICH (Fresh Water).		LOCH NESS. (Fresh Water).		
Date	Sept. 7	Sept. 7	Sept. 7	Sept. 7	Sept. 8	Sept. 8	Sept. 8
Position	Off Glastard	Laggan end, about a mile from Locks	South Basin	North Basin	At Fort Augustus	Off Aldourie	Off Aberiachan
Hour	13.50	14.50	16.10	16.40	8.10	11.10	11.50
Wind	N.E., 1	Calm	E., 1	S.W. by S., 2	W., 3	W.S.W., 5	W.S.W., 5
Weather & Sea	Bright sunshine, smooth	Sunshine, cloud, smooth	Sunshine, clouds, smooth	Sunshine, high clouds, smooth	Overcast, roughish to smooth	Overcast, very rough	Overcast, occasional sunshine, very rough
Depth	76	13	12	23	42	15	70
Temp. of Air	54·8	55·7	...	...	53·5	56·5	...
Fathoms							
0	55·9	54·6	58·5	56·7	54·8	53·8	54·0
1	55·9	54·5	58·2	...	...	...	...
2	55·2	54·7	...	...	54·8	53·7	...
3	...	54·5	...	...	...	...	...
4	...	54·6	58·0	...	...	53·7	...
5	55·6	54·2	...	56·0	54·6	...	54·0
6	...	...	57·9	...	...	...	...
7	...	54·2	...	...	...	53·6	...
8	...	...	...	...	54·5	...	...
9	...	...	57·8	...	...	53·6	...
10	55·4	53·6	57·7†	55·4	54·5	...	53·9
12	...	53·4		55·2	...	...	...
14	54·8†		...	...	47·3†	53·4	...
16	...	...	...	48·4†	...		...
18	...	...	...	...	...	...	...
20	47·0	...	...	...	46·5†	...	53·9
22	...	...	...	47·7	...	...	...
24	46·8†	...	...		...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	45·2	...	...	...	45·3†	...	53·1
32	...	...	...	...	...	...	...
34	44·6†	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	44·9	...	...	...	44·7†	...	47·8
42	...	...	...	...		...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	44·0†
50	44·0	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	43·8†	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	43·4†
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	44·1†	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	43·0†
70	...	...	...	...	...	...	
72	...	...	...	...	...	...	...
74	43·6†	...	...	...	...	...	...
76		...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH NESS. (Fresh Water).					LOCH LOCHY. (Fresh Water).	
Date	Sept. 8	Sept. 8	Sept. 8	Sept. 8	Sept. 8	Sept. 9	Sept. 9
Position	Off Castle Urquhart and Temple Pier	Off Foyers	Off north of Portclair Point	About 1 mile from Fort Augustus	Fort Augustus	Laggan, 1 mile from Locks	Off Auchnacarry (South end)
Hour	13.0	15.15	16.25	17.15	18.0	11.15	12.35
Wind	W.S.W., 5	W.S.W., 6	W.S.W., 4	W.S.W., 5	W.S.W., 5	W.S.W., 6	W.S.W., 5
Weather & Sea	Cloudy, some rain, rough	Overcast, very rough	Overcast, rough	Overcast, rain, rough	Rain, roughish	Cloud, sunshine, rain, very rough	Rain, rough
Depth	121	109	101	80	42	12	38
Temp. of Air	57·1	...	...	...	...	...	...
Fathoms							
0	54·0	54·5	54·0	51·4	47·8	55·1	54·8
1	53·9	...	...	...	...	55·1	...
2	53·8	...	...	...	47·7	...	54·8
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	54·0	...	...	48·0	47·1	55·2	54·7
6	...	...	...	...	...	55·2	...
7	...	...	...	...	...	...	...
8	...	...	...	...	46·8	...	54·0
9	...	...	...	...	...	...	...
10	53·8	54·4	52·4	46·7	46·0	55·2	52·6
12	...	...	...	...	...	55·1‖	...
14	53·6†	...	...	45·8†	45·2†		50·1†
16	...	...	...	...	...	...	49·2†
18	...	...	...	...	...	...	...
20	50·3	51·6	44·7	44·4	44·1†	...	48·1
22	...	...	...	...	...	...	...
24	49·9†	...	...	44·0†	...	...	...
26	...	...	...	...	...	...	46·6
28	...	46·8	...	...	...	...	45·8‖
30	48·4	...	43·3	43·5	43·7†	...	45·0†
32	...	...	...	...	...	...	...
34	48·2†	...	...	...	...	...	...
36	...	...	...	...	...	...	44·2†
38	47·9	...	...	...	...	...	
40	45·8	...	...	43·4	43·1†	...	...
42	...	...	...	...		...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	44·4	...	...	42·9	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	42·8†	...	...	...
60	43·5	...	43·0	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	43·1	...	42·8†	...	...	...
70	43·0	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	42·6†	...	...	...
80	43·1	...	...		...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	42·6	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	42·6	...	42·4	...	...	...	...
102	...	...		...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	42·5	...	...	...	...	...
110	42·6	...	...	...	...	...	...
120	42·1	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	LOCH ABER.	LOCH ETIVE.	SOUND OF LORNE.	LOCH LINNHE.	LOCH ABER.	LOCH EIL.	
Date . .	Sept. 10	Sept. 11	April 22	April 23	April 23	April 28	April 28
Position .	Off Inverleadle Bay	Off Glenoe Farm	Off Sheep Isle	Midway bet. Squr nan Gillean and Ru Mor	Midway bet. Corran Ferry and Fort William		About 1½ miles from Head
Hour . .	9.45	11.5	13.5	11.40	13.25	10.25	11·25
Wind . .	W.S.W., 3–5	W., 0·5	S.W., 2	N.E., 1	S.W., 1	Calm	Calm
Weather & Sea . .	Overcast, showers, roughish	Sunshine cloud, smooth	Showery, bright, slight swell	Fine, cloudy, smooth	Dull, cloudy, smooth	Smooth	Sunshine, smooth
Depth .	81	61	114	50	77	22	18
Temp. of Air	...	57·0	47·6	47·6	49·0	45·5	48·0
Fathoms							
0	54·1	55·0	45·3	45·6	46·1	45·8	45·8
1	54·0	...	...	...	...	...	...
2	54·2	55·1	...	...	...	44·9	45·2
3	54·7	55·3	...	...	...	...	...
4	54·9	...	...	...	...	...	...
5	55·0	56·1	44·9	44·9	44·9	44·7	45·0
6	55·1	...	...	...	...	...	...
7	55·2	56·1	...	...	...	...	44·9
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	55·2	55·6	45·0	44·3	44·6	44·8†	...
12	...	...	...	...	...	...	44·7
14	55·2†	54·1†	...	...	...	...	...
16	...	...	...	44·3‖	...	44·7	44·7†
18	...	...	...	...	...	...	
20	...	53·5	45·0	44·4	44·4	44·5†	...
22	...	...	...	...	...		...
24	...	52·9†	...	...	...	...	...
26	...	...	...	44·5‖	...	...	...
28	...	...	...	...	...	...	...
30	...	53·0	...	44·6‖	44·3	...	...
32	...	...	...	...	...	...	...
34	...	53·2†	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	55·2	53·5	45·0	44·8‖	44·3	...	...
42	...	...	...	...	...	...	...
44	...	53·7†	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	53·9	...	44·9‖	...	...	...
52	...	...	...		...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	44·1	...	...
58	...	...	...	...	...	...	...
60	...	54·0	45·0	...	...	...	...
62	...		...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	44·2	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	44·2	...	...
78	...	...	...	...		...	...
80	55·1	...	...	...	...	...	...
82		...	44·8	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	44·9	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...
112	...	...	45·0	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observations made 1 fathom less deep than indicated.

1888.				LOCH ETIVE.			
Date	April 20	April 21	April 23	April 24	April 24	April 24	April 25
Position	Off small Islands of Jura	Sound of Jura, off Dubh Island	Bet. Dubh-sgeir Islet and S.W. Pt. of Kerrera Island	Head	Inbhirguis-achan Chapel	Off Ru Aird Point	Bet. Ard-chattan Chapel and Stonefield Bay
Hour	9.15	13.0	10.15	17.15	17.50	18.30	13.15
Wind	N.E. by N., 6	N.E., 1–3	E.N.E., 4	N.E., 3 or 4	N.E., 3 or 4	N.E., 3	N.E., 1–2
Weather & Sea	Overcast, very rough	Overcast, rough	Overcast, rough	Sunshine, roughish	Sunshine, roughish	Sunshine, roughish	Sunshine, smooth
Depth	103	106	57	6	19	75	28
Temp. of Air	...	...	...	52·0	...	...	51·8
Fathoms							
0	44·0	43·8	43·5	49·0	47·6	45·8	45·4
1	...	...	...	49·0	...	...	45·0
2	...	...	...	49·2	47·0	...	...
3	...	43·6	43·4	49·2	...	...	44·9
4	...	...	...	49·2	...	...	...
5	44·0	43·8	43·5	49·3	48·1	45·4	...
6	...	...	...		48·1	...	...
7	...	...	...	...	...	...	44·2
8	...	...	...	...	48·3	...	...
9	...	...	...	...	...	...	...
10	43·5	43·7	43·5	...	48·3	46·2	...
12	...	...	...	...	...	...	...
14	...	...	43·4†	...	47·8	...	...
16	...	...	...	...	48·1	...	44·0†
18	...	...	...	...	47·0	...	...
20	43·3	...	...	...		45·9	...
22	...	...	...	...	...	...	...
24	...	...	43·5†	...	...	...	...
26	...	...	...	...	...	...	44·0†
28	...	...	...	...	...	...	
30	43·3	43·4	...	...	...	48·3	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	43·5	...	...	...	...
38	...	...	...	...	...	...	...
40	43·3	...	...	...	...	47·1	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	43·4	...	...	...	...
48	...	...	...	...	...	...	...
50	43·1	43·5	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	44·8	...
56	...	...	43·5	...	...	...	...
58	...	...		...	...	...	...
60	43·1	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	43·6†	...	...	...	44·5	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	43·1	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	44·8	...
76	...	...	...	...	...		...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	43·0	...	...	...	...	...	...
84	...	43·5†	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	42·9	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	43·1	...	...	...	...	...	...
104		43·6†	...	...	...	...	...
106	...		...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH ETIVE.						
Date . .	April 25	April 25	April 25	April 25	April 25	April 25	April 26
Position .	Head	¼ mile from Head	1¾ miles from Head	Inbhirguis-achanChapel	Ru Aird Point	Off Mouth of Awe	Off Mouth of Awe
Hour . .	16.10	16.25	16.50	17.20	18.10	19.10	10.50
Wind . .	N.E., down Loch, 3	N.E., 3	N.E., 2–3	N.E., 3	N.E., 3	N.E.	W.N.W., up Loch, 2
Weather & Sea . .	Sunshine, roughish	Sunshine, roughish	Sunshine, roughish	Sunshine, roughish	Sunshine, roughish	Sunshine, roughish	Sunshine, smooth
Depth .	6	13	18	22	68	9	10
Temp. of Air	...	...	50·2	...	48·0	...	...
Fathoms							
0	...	...	47·7	47·1	46·5	43·8	45·8
1	48·3	...	...	...	...	...	...
2	...	48·3	47·7	47·1	...	...	...
3	48·6	...	...	...	...	...	...
4	...	...	...	...	...	45·0	45·4
5	49·1	...	48·2	47·6	46·2	...	...
6		...	...	...	...	...	...
7	...	49·0	47·9	48·0	...	...	...
8	...	...	...	...	...	44·4	...
9	...	...	...	48·2	...		45·3
10	...	...	...	48·4†	45·3	...	
12	...	49·1	48·9	...	...	...	...
14	...		...	48·1	46·4†	...	...
16	...	...	48·9†	48·0	...	...	...
18	...	...		...	...	...	...
20	...	...	...	46·9†	46·8	...	...
22	...	...	...		...	...	...
24	...	...	...	...	48·8	...	...
26	...	...	...	...	49·0‖	...	...
28	...	...	...	...	47·8	...	...
30	...	...	...	...	47·3	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	46·2†	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	45·1	...	
42	...	...	...	...	...	...	
44	...	...	...	...	...	...	
46	...	...	...	...	44·8†	...	
48	...	...	...	...	...	...	
50	...	...	...	...	...	...	
52	...	...	...	...	...	...	
54	...	...	...	...	...	...	
56	...	...	...	...	44·8†	...	
58	...	...	...	...	...	...	
60	...	...	...	...	...	...	
62	...	...	...	...	...	...	
64	...	...	...	...	...	...	
66	...	...	...	...	44·6†	...	
68	...	...	...	...		...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

Note.—Tide was flowing out.

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1888.	LOCH ETIVE.						
Date	April 26	April 26	April 26	April 26	April 26	April 27	April 27
Position	Off second highest Quarry, upper Loch, above the Awe	Off Ru Aird Point	Head	$\frac{1}{4}$ mile from Head	$1\frac{3}{4}$ miles from Head	Off Mouth of Awe	Second Quarry above the Awe
Hour	11.20	12.15	15.30	16.5	16.25	10.25	10.45
Wind	W.N.W., up Loch, 2	W.N.W., 2	W., 2	W., 2–3	W., 1	W.N.W., 4–5	W.N.W., 4–5
Weather & Sea	Sunshine and cloud, smooth to roughish	Cloud to sunshine, roughish to smooth	Cloudy, roughish to smooth	Overcast, showers, roughish	Showers, gusts of wind, smooth	Overcast, rain, gale, rough	Overcast, showers, rough
Depth	55	70	8	13	17	11	...
Temp. of Air	...	...	...	...	48·7 (wet)	...	...
Fathoms							
0	46·2	46·3	48·5	...	47·0	45·3	46·2
1	46·0	...	47·9	...	47·0	...	...
2	...	...	47·8	47·9	47·1	...	46·1
3	45·1	...	47·9	...	...	...	...
4	...	...	...	...	...	...	47·1
5	45·6	45·2	47·9	...	...	45·2	47·0
6	...	...	...	...	47·7	...	46·1
7	...	...	48·1	47·8	...	...	...
8	...	...		...	...	...	45·1
9	...	...	...	...	...	...	...
10	45·0	47·0	...	...	48·3†	44·8	45·1
12	...	...	...	48·8	...		...
14	45·1†	47·0†	...		...	...	45·1†
16	45·2†	...	...	...	48·8	...	...
18	45·1†	...	...	...		...	...
20	47·3	47·7	...	...	...	...	45·1
22	46·7†	48·3	...	...	...	...	...
24	46·1†	48·5	...	...	...	...	45·1†
26	...	48·3	...	...	...	...	...
28	...	47·7	...	...	...	...	...
30	45·2	47·1	...	...	...	...	45·0
32	...	...	...	...	...	...	...
34	45·1	46·4†	...	...	...	...	44·8†
36	...	...	...	...	...		...
38	...	...	...	...	...		...
40	...	45·1		...	...		...
42	...	...		...	...		...
44	45·0	...		...	...		44·8†
46	...	...	*Note.*—The Temperature of the small stream at the head of the Loch, at its mouth, was 49·1.	...	...	*Note.*—One of the burns running in near the Awe had a Temperature of 45·8, and another, 44·5 at 10 A.M.	
48	...	44·9†		...	...		
50	...	...		...	...		
52	...	...		...	...		
54	44·8	...		...	...		*Note.*—Surface up Loch from this station every few minutes
56		...		...	...		
58	...	44·7†		...	...		
60	...	...		...	...		
62	...	...		...	...		
64	...	...		...	...		
66	...	...		...	...		
68	...	44·6†		...	...		46·2
70	...			...	...		47·2
72	...	...		...	...		47·4
74	...	...		...	...		47·2
76	...	...		...	...		46·5
78	...	...		...	...		47·2
80	...	...		...	...		47·2
82	...	...		...	...		47·5
84	...	...		...	...		Average,
86	...	...		...	...		47·05
88	...	...		...	...		
90	...	...		...	...		
92	...	...		...	...		
94	...	...		...	...		...
96	...	...		...	...		...
98	...	...		...	...		...
100	...	...		...	...		...
102	...	...		...	...		...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH ETIVE.						
Date	April 27	April 27	April 27	April 27	April 27	April 27	April 27
Position	$1\frac{3}{4}$ miles from Head	Head	$\frac{1}{4}$ mile from Head	Inbhir-guisachan Chapel	Close to Lee Shore, south of Mouth of Kinglas	Weather Shore opposite	Off Ru Aird Point
Hour	12.55	13.30	13.45	14.25	15.0	15.20	16.0
Wind	W., gusts all directions, squalls, 6–7	W., gusts all directions, squalls, 7–8	W., gusts, 0–8	W.N.W., 5–6	N.W., 4–5	N.W., 4–5	W.N.W., blowing up, 4–5
Weather & Sea	Cloud, sunshine, showers, rough	Sunshine, cloud	Sunshine, rough to smooth	Sunshine, cloud, rough	Overcast, sunshine, rough	Overcast, sunshine, rough	Overcast, rough
Depth	18	6	16	20	13	10	66
Temp. of Air	50·9	...	...	...	...	...	...
Fathoms							
0	47·3	45·2	...	47·0	46·6	47·1	46·5
1	...	46·0	...	...	...	47·0	...
2	47·1	47·2	...	...	46·5	47·1	...
3	...	47·1	...	46·9	...	...	...
4	...	46·9	...	...	...	47·1	...
5	47·1	47·0	47·0	...	46·6	47·3	46·0
6	...		...	46·9	...	...	...
7	47·1	...	...	47·0	47·3	47·2	...
8	...	...	...	...	...	...	46·1
9	...	...	...	47·6	...	...	...
10	47·6	...	48·8	48·3†	47·5	47·3	48·0
12	...	...	...	48·3†	48·0		48·1†
14	...	...	48·7†	...		...	48·0†
16	48·5†	...		47·6	...	...	...
18			...	47·4†	...	...	47·7
20	...		...		...	...	48·2
22	...		...	...	...	...	...
24	...		...	...	...	...	47·1†
26	...		...	...	...	...	...
28	...		...	...	...	...	...
30	...		...	...	...	...	46·1
32	...		...	...	...	...	...
34	...		...	...	...	...	45·1†
36	...		...	...	...	...	...
38	...		...	...	...	...	...
40	...		...	...	...	...	44·7
42	...		...	...	...	...	...
44	...		...	...	...	...	44·8†
46	...		...	...	...	...	...
48	...		...	...	...	...	...
50	...		...	...	...	...	...
52	...		...	...	...	...	...
54	...		...	...	...	...	44·7†
56	...		...	...	...	...	...
58	...		...	...	...	...	...
60	...		...	...	...	...	...
62	...		...	...	...	...	...
64	...		...	...	...	...	44·6†
66	...		...	...	...	...	
68	...		...	...	...	...	...
70	...		...	...	...	...	...
72	...		...	...	...	...	...
74	...		...	...	...	...	...
76	...		...	...	...	...	...
78	...		...	...	...	...	...
80	...		...	...	...	...	...
82	...		...	...	...	...	...
84	...		...	...	...	...	...
86	...		...	...	...	...	...
88	...		...	...	...	...	...
90	...		...	...	...	...	...
92	...		...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

Note.—The water to-day was quite fresh at the surface at head of the Loch. Yesterday it was salt, and also the day before.

† Observation made 1 fathom deeper than indicated.

1888.	LOCH ETIVE.						
Date	April 30	April 30	Ap i 30	April 30	April 30	April 30	April 30
Position	Bet. Ard-chattan Chapel and Stonefield Bay	Off Mouth of Awe	Second Quarry above the Awe	Off Ru Aird Point	Head	¼ mile from Head	Inbhir-guisachan Chapel
Hour	10.30	11.30	11.45	12.20	14.15	14.30	15.20
Wind	S.S.E., 2	S.W. by S., 1–2	S.W. by S., 1–2	Calm	S.W., 1	S.W., 1–2	S.W., 1
Weather & Sea	Overcast, roughish	Overcast, showers, smooth	Overcast, showers, smooth	Overcast, smooth	Overcast, smooth	Cloud, sunshine, smooth to roughish	Overcast, smooth
Depth	19	9	62	73	6	14	20
Temp. of Air	46·6	48·0	...	49·2	...	51·1	52·0
Fathoms							
0	45·2	46·1	47·0	46·0	45·3	46·0	47·0
1	...	...	...	...	47·0	47·1	...
2	45·1	...	46·3	...	47·1	47·0	47·0
3	...	46·0	...	...	47·1	47·1	...
4	...	...	...	...	47·1	...	...
5	45·0	...	45·7	46·8	47·4	...	46·8
6	...	...	...	...		...	...
7	...	...	45·8	46·3	...	...	...
8	45·0	45·5	...	...	...	48·3	...
9	...		...	...	...	...	47·2
10	...	...	45·8	46·9	...	...	...
12	45·0†	...	...	46·8	...	48·5†	...
14	...	...	46·8 / 47·0†	46·8†	...		47·9†
16	44·8	...	47·1	47·9†	...	...	...
18		...	45·6	...	...	...	47·7†
20		...	46·1	47·9	...	...	
22		...	...	...	...	...	...
24		...	45·6†	46·9†	...	...	...
26		...	...	...	...	...	...
28		...	...	...	...	...	...
30		...	45·2	45·6	...	...	...
32		...	...	...	...	...	...
34		...	...	45·1†	...	...	...
36		...	...	...	...	...	...
38		...	...	...	...	...	...
40		...	45·1†	44·7	...	...	...
42		...	...	...	...	...	...
44		...	...	...	...	...	...
46		...	...	...	...	...	...
48		...	...	...	...	...	...
50		...	45·2†	...	...	...	...
52		...	...	45·0	...	...	...
54		...	...	...	...	...	...
56		...	...	...	...	...	...
58		...	...	...	...	...	...
60		...	45·2†	...	...	...	...
62		...		45·1	...	...	...
64		...	...	...	...	...	...
66		...	...	...	...	...	...
68		...	...	...	...	...	...
70		...	...	...	...	...	...
72		...	...	45·0	...	...	...
74		...	...		...	...	...
76		...	...	...	...	...	...
78		...	...	...	...	...	...
80		...	...	...	...	...	...
82		...	...	...	...	...	...
84		...	...	...	...	...	...
86		...	...	...	...	...	...
88		...	...	...	...	...	...
90		...	...	...	...	...	...
92		...	...	...	...	...	...
94		...	...	...	...	...	...
96		...	...	...	...	...	...
98		...	...	...	...	...	...
100		...	...	...	...	...	...
102		...	...	...	...	...	...
104		...	...	...	...	...	...
106		...	...	...	...	...	...
108		...	...	...	...	...	...

Note.—In Oban Bay at 8.20 A.M. the surface water was 44·7; and to Loch Etive the following were observed:—44·4; 45·1; 45·0. The water at Oban and outside was very pure and clear, like deep-sea water.

† Observation made 1 fathom deeper than indicated.

1888.	LOCH ABER.	MULL SOUND.	LOCH SUNART.				SOUND OF MULL.
Date	May 1	May 1	May 4	May 4	May 4	May 4	May 5
Position	Near centre of Loch	Bet. Morven and Lismore	Bet. Charna and Eil na Gillean	Off Ru Arderinish	Off Ru Strone na Saoibhaidh	Off Strontian Head	Fishnish Bay
Hour	11.20	18.5	9.0	10.0	11.10	11.50	9.20
Wind	Calm, W., 0·5	W.N.W., 4	W.N.W., 3	W.N.W., 3	W.N.W., 3–4	W.N.W., 1–2	W.N.W., 4–6 or 7
Weather & Sea	Overcast, showers, smooth	Overcast, showers, rough	Sunshine, roughish	Sunshine, roughish	Sunshine, cloud, showers, roughish	Sunshine, smooth	Hail showers, rain, rough
Depth	85	105	63	49	51	10	58
Temp. of Air	51·0	...	44·0	46·0	46·2	...	41·2
Fathoms							
0	45·0	44·5	45·1	45·1	45·4	43·8	44·1
1	...	...	...	...	...	44·0	...
2	43·9	...	45·1	45·1	45·1	45·0	44·1
3	...	...	...	...	...	44·8	...
4	...	...	...	...	...	44·8	...
5	43·8	...	44·9	44·9	44·8	...	44·1
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	44·7	...
10	43·9	43·9	44·8	44·4	44·7		44·0
12	...	...	...	...	...	...	...
14	43·9†	...	...	44·2†	44·4†	...	44·1†
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	44·1†
20	43·7	45·8	44·4	44·1	44·3	...	...
22	...		...	...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	44·1	...	...	...
30	43·7	...	44·4	...	44·3	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	44·0†
38	...	...	...	44·1	...	...	...
40	43·4	...	...	...	44·2	...	...
42	...	...	44·4	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	44·1†
48	...	...	...	44·1	...	...	...
50	43·4	...	...		44·2	...	...
52	...	...	44·4	...		...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	44·2†
58	...	...	...	...	...	...	
60	...	...	...	...	...	...	...
62	...	...	44·4	...	...	...	...
64	43·4	...		...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	43·2†	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	43·1†	...	...	...	...	...	...
82		...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	FIRTH OF LORNE.			LOCH ETIVE			
Date	May 9	May 10	May 11	May 14	May 14	May 14	May 14
Position	Between Mull and Kerrera	Between Mull and Sheep Island	Between Loch Buy and Island of the Sea	Between Ardehattan and Stone-field Bay	Off Mouth of Awe	Second Quarry above the Awe	Off Ru Aird Point
Hour	11.0	13.55	14.50	10.10	11.10	11.30	12.30
Wind	N.W., 1	S., 0·5	S., 1	N.W., 2	N.W., 2	N.W., 3	N.W., 2
Weather & Sea	Overcast, roughish	Bright, swell	Bright, swell	Partially overcast, smooth	Clear, smooth	Bright, smooth	Sunshine and eloud, smooth
Depth	117	123	33	26	10	64	73
Temp. of Air	46·5	51·2	49·5	46·0	51·0	48·1	49·0
Fathoms							
0	44·5	46·8	46·7	47·0	47·8	49·9	51·0
1	...	...	...	47·0	...	50·0	51·0
2	...	...	45·1	...	...	47·1	47·3
3	...	...	...	46·5	...	47·4	...
4	...	...	...	...	46·4	46·5	...
5	...	44·6	...	46·7	...	46·4	46·2
6	...	...	...	...	...	46·5	...
7	...	...	44·7	...	...	...	46·2
8	...	...	...	...	...	47·6	...
9	...	...	...	...	46·6	...	...
10	44·3	44·4	...	...		47·0	46·9
12	...	...	44·7	...	...	47·6	47·9†
14	...	...	...	46·3†	...	...	47·7†
16	...	...	...	...	...	47·4	47·5†
18	...	...	...	...	...	...	...
20	44·2	44·3	...	...	...	46·1	46·6
22	...	...	44·4	...	...	...	...
24	...	...	...	46·3†	...	...	...
26	...	...	...		...	45·7	...
28	...	...	...	...	...	...	...
30	44·3	...	...	...	...	45·1	45·0
32	...	...	44·3	...	...	...	...
34	...	...		...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	44·2	44·3	...	...	...	...	44·9
42	...	...	...	...	...	45·3†	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	44·2	...	...	...	...	...	...
52	...	...	...	...	...	45·3†	45·2
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	44·2	44·2	...	...	...	...	...
62	...	...	...	...	...	45·4†	45·2
64	...	...	...	...	...		...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	44·1	...	...	...	...	...	...
72	...	...	...	...	...	...	45·2
74	...	...	...	...	...	...	
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	44·2	...	...	...	...	...	...
82	...	44·3	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	44·2	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	44·3	...	...	...	...	...
104	...	...	...	...	...	...	...
106	44·2	...	...	...	...	...	...
108	...	...	...	...	...	...	...
116	44·1	...	...	...	...	...	...
122		44·2	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

	LOCH ETIVE.						
Date	May 14, 1888.	May 3, 1887	May 3, 1887	May 3, 1887	May 3, 1887	May 3, 1887	May 3, 1887
Position	1½ miles from Head	Mouth, Lochnell Bay	Off Ardchattan Church, and Kilmaronaig Point	Midway bet. Ards Point and Eil Durains	Off Ru Aird	1 mile from head, off Ru Aird Trileadham	S.W. of Sgeir-lag
Hour	14.5	10.0	10.40	11.30	12.30	13.35	15.0
Wind	N.W., 1–3	Calm	N., 0·5	Calm	W., 1	Calm	W., 2
Weather & Sea	Squalls, overcast, smooth	Sunshine, blue sky, smooth	Bright, sunshine, smooth	Bright sunshine, smooth	Sunshine & cloud, smooth to roughish	Cloudy, smooth	Cloudy, roughish
Depth	17	20	18	33	67	18	61
Temp. of Air	51·2	...	...	...	...	...	...
Fathoms							
0	50·3	46·5	47·7	48·6	48·4	48·6	...
1	...	46·0	46·7	46·2	47·0	47·1	...
2	47·5	...	...	...	45·7	...	...
3	...	...	...	45·5	45·3	46·2	...
4	46·6	...	...	...	...	...	...
5	46·8	...	...	45·4	45·3	46·2	...
6	47·0	...	...	...	...	...	...
7	...	...	46·1	...	...	45·7	...
8	...	...	...	45·4	...	...	...
9	...	45·2	...	...	...	...	...
10	47·6	...	...	...	44·3	...	45·1
12	48·1	...	...	45·3	...	45·3	...
14	...	...	...	...	44·7†	...	...
16	47·3	...	45·9†	...	...	45·3†	...
18		45·2†		45·3	...		...
20	...		...	...	45·0	...	45·2
22	...	...	...	45·2	...	...	...
24	...	...	Surface temperature mean of seven readings.	...	...	...	...
26	...	...		...	...	...	...
28	...	...		45·2	...	...	...
30	...	...		...	46·1	...	46·0
32	...	...		45·2	...	...	...
34	...	...			...	...	...
36	...	...		...	...	...	...
38	...	...		...	...	...	...
40	...	...		...	47·5	...	47·4
42	...	...		...	...	...	...
44	...	...		...	...	...	...
46	...	...		...	47·6	...	...
48	...	...		...	...	...	...
50	...	...		...	...	...	47·5
52	...	...		...	...	...	...
54	...	...		...	...	...	...
56	...	...		...	47·5	...	...
58	...	...		...	...	...	...
60	...	...		...	...	...	47·5
62	...	...		...	...	...	
64	...	...		...	...	...	...
66	...	...		...	47·6	...	...
68	...	...		...		...	...
70	...	...		...		...	...
72	...	...		...		...	...
74	...	...	...	...		...	...
76	...	...	...	...	Surface temperature mean of four readings.	...	...
78	...	...	...	...		...	...
80	...	...	...	...		...	...
82	...	...	...	...		...	...
84	...	...	...	...		...	...
86	...	...	...	...		...	...
88	...	...	...	...		...	...
90	...	...	...	...		...	...
92	...	...	...	...		...	...
94	...	...	...	...		...	...
96	...	...	...	...		...	...
98	...	...	...	...		...	...
100	...	...	...	...		...	...
102	...	...	...	...		...	...
104	...	...	...	...		...	...
106	...	...	...	...		...	...

1887.	ARRAN BASIN.	GARELOCH.				ESTUARY.	LOCH LONG.
Date . .	August 1	August 6	August 6	August 6	August 6	August 6	August 7
Position .	Off Garroch Head	Head	Off Shandon	Row, off inside Spit	Row, off outside Spit	Off Greenock	Arrochar
Hour . .	18.10	13.45	14.15	16.20	16.45	17.40	13.45
Wind . .	W.S.W., 1	Calm	Calm	Calm	Calm	Calm	W., 2
Weather & Sea . .	Overcast, smooth	Raining, smooth	Rain, mist, overcast, smooth	Rain, smooth	Rain, smooth	Rain, smooth	Cloudy, sunshine, ripple
Depth .	61	10	22	18	11	$4\frac{1}{2}$	12
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	57·4	60·2	60·0	58·1	57·0	57·7	59·6
1	...	60·0	59·8	...	...	...	59·7
2	57·1	58·9	59·0	57·8	56·8	...	...
3	...	...	...	...	56·5	55·4*	...
4	...	58·2	58·2	57·7	56·0		59·9
5	56·1	...	58·1	...	55·7	...	...
6	...	...	...	...	...	...	59·3
7	...	57·9	...	57·6	55·2	...	...
8	56·2	...	57·7	...	55·1	...	...
9	...	57·8	...	...	...	...	56·1
10	56·0		57·5†	...	54·1	...	54·0†
12	56·0	...	...	...		...	
14	55·6†	...	57·1†	57·4	...	...	...
16	...	...	...	57·4†	...	...	...
18	...	...	...		...	...	...
20	52·4	...	54·7†	...	...	...	...
22	...	...		...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	50·0	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	48·0	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	48·1	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	47·9	...	...	...	...	...	...
62		...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

* Observation made $\frac{1}{2}$ fathom deeper than indicated. † Observation made 1 fathom deeper than indicated.

1887.	LOCH LONG.	DUNOON BASIN.		LOCH GOIL.		DUNOON BASIN.	ESTUARY.
Date	August 7	August 7	August 7	August 7	August 7	August 7	August 8
Position	Off Thornbank	Dog Rock	Entrance, Loch Goil	Off Stuckbeg	Head	Off Coulport	Off Roseneath Point
Hour	14.0	15.40	16.5	16.40	17.12	18.20	9.10
Wind	S.W., 3	W., 3	W., 3	Calm	W., 2	W., 6	N.W., 7
Weather & Sea	Cloudy, roughish	Cloudy, roughish	Cloudy, showers, roughish	Sunshine, clouds, smooth	Cloudy, smooth	Overcast, rough	Mist, rain, rough
Depth	31	50	...	44	26	39	10
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	59·4	58·1	58·6	58·6	58·3	58·2	57·5
1	...	...	...	...	...	...	...
2	...	58·2	...	58·3	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	57·5
5	58·2	55·5	56·1	55·3	56·3	56·0	...
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	57·3
10	54·2	53·5	52·8	53·4	53·4	54·5	
12	...	...		...	...	...	...
14	52·0†	...	...	52·3†	51·9†	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	52·2	...
20	51·1	52·0	...	...	47·9	...	...
22	...	...	...	46·8†	...	...	...
24	...	...	...	...	47·8†	...	...
26	...	...	...	...		...	...
28	...	50·0†	...	...	...	50·4	...
30	47·1	49·8	...	...	...	...	...
32		...	...	46·3†	...	...	...
34	...	...	...	45·8†	...	...	...
36	...	...	...	...	...	...	...
38	...	49·4†	...	...	...	49·0	...
40	...	...	...	...	...		...
42	...	...	...	45·4†	...	...	...
44	...	...	...		...	...	...
46	...	...	...	...	...	...	...
48	...	49·0†	...	...	...	...	...
50	...		...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	DUNOON BASIN.	HOLY LOCH.		DUNOON BASIN.	KYLES OF BUTE.		
Date . .	August 8	August 8	August 8	August 8	August 8	August 8	August 9
Position .	Mouth of Loch Long	Head	Mouth	Gantock Beacon	Bogany Point	Off Strone Point	Off Burnt Islands
Hour . .	10.5	10.45	11.0	14.40	16.15	...	11.0
Wind .	N.W., 5	N.W., 6	N.W. gale, 7	N.W. gale, 5 or 6	N.W., 4	N.W., 5	N., 3
Weather & Sea . .	Rain, mist, rough	Rain, mist, rough	Rain, mist, rough	Rain, mist, rough	Rain, mist, rough	Rain, mist, rough	Cloudy, smooth
Depth .	31	12	17	48	27	16	21
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	56·8	55·1	55·4	52·5	57·0	56·0	57·4
1	...	55·0	...	...	...	...	...
2	56·8	...	...	55·7	56·9	...	56·1
3	...	...	...	...	...	55·8	...
4	...	...	55·7	...	...	...	...
5	56·6	...	...	55·5	...	55·3	54·7
6	...	54·1	55·8	...	54·6	...	...
7	...	...	...	55·3	...	...	...
8	...	54·1	...	...	...	55·2	...
9	...	...	53·9	...	...	...	...
10	55·3	53·6†	...	55·2	54·1	...	53·2
12	...		...	54·1	53·6†	53·1†	...
14	...	...	53·1	54·5†	...	52·7†	52·6†
16	...	...	52·6	...	51·9		...
18	...	...		...	...	...	...
20	54·2	...	...	53·1	51·1	...	51·9
22	...	...	...	...	...	...	
24	...	...	...	...	...	...	...
26	...	...	...	52·3†	50·0	...	...
28	...	...		...		...	...
30	50·9	...		...	...	...	...
32		...	The wind was blowing very hard down the Loch, and it seems as if colder water were drawn in at the bottom from the deeper water of the Dunoon basin.	...	...	...	...
34	...	...		...	...	...	...
36	...	...		52·4†	...	...	...
38	...	...		...	...	...	...
40	...	...		...	...	...	...
42	...	...		...	...	...	...
44	...	...		...	...	...	...
46	...	...		52·2†	...	...	...
48	...	...			...	...	...
50	...	...		...	...	...	...
52	...	...		...	...	...	...
54	...	...		...	...	...	...
56	...	...		...	...	...	...
58	...	...		...	...	...	...
60	...	...		...	...	...	...
62	...	...		...	...	...	...
64	...	...		...	...	...	...
66	...	...		...	...	...	...
68	...	...		...	...	...	...
70	...	...		...	...	...	...
72	...	...		...	...	...	...
74	...	...		...	...	...	...
76	...	...		...	...	...	...
78	...	...		...	...	...	...
80	...	...		...	...	...	...
82	...	...		...	...	...	...
84	...	...		...	...	...	...
86	...	...		...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	KYLES OF BUTE.	ARRAN BASIN.				KYLES OF BUTE.	LOCH STRIVAN.
Date . .	August 9	August 12	August 12	August 12	Augus 12	August 13	August 13
Position .	Loch Ridun	Off Ardlamont Point	Inchmarnock Water	Bet. Brodick and Corry	Off Largybeg Point	Burnt Islands	Opposite Glenstrivan
Hour . .	11.0	13.45	14.35	17.0	19.20	15.0	18.25
Wind . .	N.E., 3	Calm	Calm	N.W., 1	Calm	N.E., 2	N.E., 3
Weather & Sea .	Cloudy, smooth	Overcast, smooth	Overcast, smooth	Overcast, rain, smooth	Overcast, rain, smooth	Sunshine, smooth	Sunshine, roughish
Depth .	10	34	86	96	49	18	35
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	57·5	53·9	55·0	56·1	57·1	55·0	56·2
1	...	...	...	...	...	...	...
2	...	53·6	...	...	...	...	56·2
3	...	...	54·3	55·8	...	...	...
4	...	...	...	...	...	...	...
5	55·3	53·5	54·1	56·1	56·9	...	56·1
6	...	...	...	...	...	...	...
7	...	53·2	...	...	...	52·6	55·1
8	...	...	53·6	...	...	...	...
9	...	...	...	...	...	...	...
10	53·9	...	53·5	56·0	56·6	...	54·8
12		52·6†	53·7†	...	...	...	...
14	...	...	53·2†	55·8†	56·4†	...	53·7
16	...	52·1†	52·5†	...	56·4	51·1†	50·4†
18	...	...	...	...	55·7		...
20	...	...	53·6	53·6	52·9	...	50·1
22	...	51·9†	...	...	51·1†	...	...
24	...	...	53·4†	51·5†	...	...	49·4
26	...	...	...	...	...	...	...
28	...	...	...	...	50·6	...	...
30	...	49·9	51·3	...	...	...	48·9
32	...	49·1†	49·4	...	...	...	48·8
34	...		49·0†	50·1†	...	...	47·9‖
36	...	...	...	...	...	...	
38	...	...	...	...	49·4	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	49·2†	48·6†	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	49·0	...	...
50	...	...	...	...		...	...
52	...	...	...	...	...	...	...
54	...	...	48·4†	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	47·8	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	47·7†	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	47·9	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	47·3†	47·3†	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	47·4	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	46·8†	47·3†	...	...	...
86	...	...		...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	47·0†	...	...	...
96	...	...	...		...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	LOCH STRIVAN.	ARRAN BASIN.		LOCH FYNE.			
Date	August 14	August 14	August 15	August 15	August 15	August 15	August 15
Position	Head	Off Skate Island	Off Kilfinnen Bay	Off Otter Beacon	Off Gortans	Off Paddy Rock	Off Furnace
Hour	15.40	19.40	10.45	11.20	12.5	13.5	13.45
Wind	N.E., 2	N.W., 3	N., 1	N., 1	S.W., 1	S.W., 1	S.W., 2
Weather & Sea	Overcast, smooth	Clear, sunshine, roughish	Cloud, sunshine, smooth	Cloudy, sunshine, smooth	Cloudy, sunshine, smooth	Cloudy, sunshine, smooth	Cloudy, smooth
Depth	10	104	68	21	34	16	35
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	54·8	53·5	53·9	55·9	55·6	54·8	55·0
1	54·8	...	53·6	53·9	54·6	55·0	55·0
2	...	...	53·3	53·9	54·0	54·4	54·4
3	54·1	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	54·0	53·4	52·2	51·9	52·4	52·4	52·6
6	...	...	...	...	...	...	...
7	...	...	...	52·0	...	51·5	...
8	50·0	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	49·5	53·0	52·2	51·9	51·5	51·5	51·5
12		...	...	...	51·2†	50·9†	...
14	...	...	51·2†	51·1†	51·0†	50·2†	51·3
16	...	...	...	...	50·8†		...
18	...	...	...	...	...	...	...
20	...	50·8	50·8	50·9	50·9	...	51·0‖
22	...	...	...		50·4†	...	...
24	...	...	...	...	...	...	50·7
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	49·1
30	...	50·1	49·7	...	50·0	...	47·6
32	...	...	...	...	50·0†	...	...
34	...	...	...	...		...	46·1
36	...	...	...	...	...	...	
38	...	...	...	...	...	...	...
40	...	48·7	48·5	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	47·9†	...	...	...	...
48	...	...	...	...	...	...	...
50	...	48·1	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	47·6†	...	...	...	...
58	...	...	...	...	...	...	...
60	...	48·1	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	47·2†	...	...	...	...
68	...	...		...	...	...	...
70	...	47·2	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	47·1†	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	47·2†	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	47·1†	...	...	...	...	...
104	...		...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	LOCH FYNE.					ARRAN BASIN.	
Date . .	August 15	August 15	August 15	August 16	August 16	August 16	August 16
Position .	Off Strachur	Off Cuill	Dunderave Castle	Off Inveraray	Off Gortans	Off Skate Island	Garroch Head
Hour . .	14.45	17.20	17.50	10.0	12.35	15.15	18.5
Wind . .	S.W., 1	S.W., 2	S.W., 2	Calm	S.W., 1	S.W., 2	Calm
Weather & Sea .	Cloudy, smooth	Cloudy, smooth	Cloudy, smooth	Sunshine, warm, smooth	Sunshine, clouds, smooth	Sunshine, bright, smooth	Sunshine, smooth
Depth .	75	16	35	60	34	104	61
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	55·9	55·7	56·1	57·0	55·4	55·5	56·8
1	55·6	55·8	...	...	...	...	56·6
2	...	...	55·4	55·6	...	...	55·5
3	...	55·4	...	...	...	54·1	55·4
4	...	...	...	...	...	...	...
5	53·3	55·3	53·4	53·2	52·3	54·2	55·4
6	...	...	...	...	...	...	...
7	...	...	...	52·1	...	...	...
8	...	52·4	...	...	...	...	54·3
9	...	...	...	...	...	...	...
10	51·5	...	51·3	51·0	51·7	53·7	54·1
12	...	50·1†	...	...	51·5†	...	53·5
14	50·7†	49·6†	50·2	50·2†	...	53·3†	52·6†
16	...		...	...	...	...	...
18	...	...	...	...	...	...	...
20	50·4	...	48·9	49·8	51·0	52·1	52·2
22	...	...	...	...	51·0†	...	...
24	48·2†	...	48·3	48·0†	...	...	51·5†
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	47·0	...	47·1	46·8	...	50·2	51·3
32	...	...	...	...	50·1†	...	...
34	...	...	46·3	46·3†		...	...
36	...	...		...	...	...	...
38	...	...	...	46·0†	...	...	...
40	46·8	...	...	...	...	49·6	51·1
42	...	...	...	...	...	...	...
44	...	...	...	46·1†	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	45·6†	...	...	...
50	45·5	...	...	...	...	48·5	51·1
52	...	...	...	...	...	...	...
54	45·2	...	...	45·2†	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	45·2†	...	...	...
60	...	...	...		...	...	50·6
62	...	...	...	...	...	48·6†	
64	45·3	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	45·1	...	...	...	...	...	...
76		...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	47·5†	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	47·1†	...
104	...	...	...	...	...		...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	ARRAN BASIN.	PLATEAU.	ARRAN BASIN.				
Date . .	August 17	August 17	Sept. 12	Sept. 20	Sept. 20	Sept. 20	Sept. 20
Position . .	Off Imachar Point, Kilbrennan Sound	Bet. Sanda and Pladda	Skate Island, south of 106 fathoms	Garroch Head	2 miles towards Brodick	Off Brodick (deep hole)	2¼ miles towards Brodick
Hour . .	16.0	19.0	13.0	9.55–10.15	10.35–10.45	11.25–11.50	12.15–12.25
Wind .	N.W., 4	N.N.W., 5	N.W., 4	...	N.W., 1–2	N.N.W., 2–3	N.N.W., 2
Weather & Sea . .	Sunshine, rough	Sunshine, very rough	Overcast, rough	Bright, smooth	Bright, smooth	Slight swell	Smooth
Depth .	75	24	40	61	46	80	45
Temp. of Air	...	...	53·1	56·0 dry 51·8 wet	...	56·0 dry 54·0 wet	56·0 dry 54·0 wet
Fathoms							
0	57·1	57·1	54·4	54·9	55·0	55·0	55·3
1	...	57·2	...	...	...	...	...
2	57·1	...	...	54·7	...	...	...
3	...	57·2	...	...	...	...	...
4	...	...	...	...	...	...	...
5	57·0	57·1	...	54·7	...	...	...
6	...	...	...	...	...	...	...
7	56·0	56·9	...	...	...	...	...
8	...	57·0	...	...	...	...	...
9	...	...	...	...	...	...	...
10	55·8	55·3	54·0	54·1	54·7	...	...
12	...	56·6‖	...	...	...	...	...
14	53·9†	54·9‖	...	...	55·0†	...	55·1
16	...	55·1	...	...	...	...	...
18	...	55·0	53·5†	...	...	...	...
20	52·0	...	53·2	54·2	...	53·7	...
22	...	55·0†	...	...	...	...	...
24	...		...	...	53·5†	...	54·1
26	...	...	...	...	...	...	...
28	...	...	52·2†	...	...	...	...
30	50·2	...	...	54·0	...	53·2	...
32	...	...	...	...	...	...	...
34	...	...	...	...	52·4†	...	...
36	...	...	...	...	...	...	...
38	...	...	51·8†	...	...	...	...
40	49·1	...		53·3	...	52·2	...
42	...	...	...	...	...	...	...
44	...	...	...	...	52·0†	...	51·4
46	...	...	...	...		...	
48	...	...	...	...	...	...	...
50	...	...	...	53·2	...	51·1	...
52	...	...	...	...	...	...	...
54	48·9	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	50·1†	...
60	...	...	...	52·9	...	...	...
62	...	...	...		...	...	...
64	49·0	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	50·1†	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	48·6	...	...	...	...	...	...
76		...	...	...	...	...	...
78	...	...	...	...	...	49·1†	...
80	...	...	...	...	...	48·7	...
82	...	...	...	...	...		...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	ARRAN BASIN.						
Date	Sept. 20	Sept. 20	Sept. 20	Sept. 20	Sept. 20	Sept. 20	Sept. 20
Position	Brodick Bay	Brodick Bay, close inshore	6 miles East Holy Island	9 miles East Holy Island	13 miles East Holy Island	About 1 mile W. by S. of Lappoch Beacon	Off Irvine
Hour	12.50–13.0	13.15–13.20	14.17–14.34	15.10–15.20	15.55–16.3	16.30–16.37	16.55–17.0
Wind	N.N.W., 2	...	N.W. by N., 0·5	Northerly, 0·5	Northerly, 0·5	Northerly, 0·5	W. by N., 0·5
Weather & Sea	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Depth	23½	5	63	48	32	13	6
Temp. of Air	57·0 dry 52·8 wet	57·0 dry 52·8 wet	57·3 dry 55·0 wet	57·3 dry 55·0 wet	58·0 dry 55·3 wet	58·0 dry 55·3 wet	58·0 dry 55·3 wet
Fathoms							
0	55·5	55·9	56·0	56·0	56·1	55·9	56·0
1	...	56·2	...	...	...	...	...
2	55·3*	...	...	...	...	55·8	56·2
3	...	...	...	...	...	...	...
4	...	55·4	...	...	...	...	...
5	...	...	...	...	...	...	55·4
6	...	...	...	...	...	...	...
7	...	...	...	55·5	...	56·0	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	...	55·2	...	55·2†	...	...
12	55·3*	...	...	...	...	55·8	...
14	55·3†	...	...	...	...	...	...
16	...	...	...	54·6†	...	...	...
18	54·9	...	...	...	...	...	...
20	...	...	54·8	...	55·9†	...	...
22	53·4*	...	...	...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	53·0†	...	...	...
28	...	...	...	...	...	...	...
30	...	...	53·2	...	55·1†	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	52·7†	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	51·5	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	51·8†	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	52·0	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	51·1	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

* Observation made ½ fathom deeper than indicated. † Observation made 1 fathom deeper than indicated.

1887.	ARRAN BASIN.			PLATEAU.			
Date . .	Sept. 20	Sept. 21	Sept. 21	Sept. 21	Sept. 21	Sept. 21	Sept. 21
Position .	Lady Island, E.S.E., 1 mile	5 miles W.N.W. of Ayr	4 miles W. by N. Heads of Ayr	6 miles N.W. Turnberry Light	Ailsa, W. by S.	Ailsa, W. by S., close to	8 miles W. by N. of Ailsa
Hour . .	17.40–17.45	8.40–8.45	9.30–9.38	10.25–10.45	11.30–11.50	12.35–12.45	14.15–14.25
Wind . .	N.N.W., 1	South, 1·2	S.S.E., 2	0	0	0	0
Weather & Sea . .	Haze, bright, smooth	Misty, smooth	Slight mist, smooth	Mist, smooth	Mist, very slight swell	Mist, smooth	Mist, swell
Depth .	18	11	24	31	29	33	28½
Temp. of Air .	56·0 dry 54·2 wet	52·3 dry 50·5 wet	53·2 dry 51·5 wet	54·0 dry 51·5 wet	55·0 dry 51·4 wet	55·3 dry 52·3 wet	55·5 dry 52·0 wet
Fathoms							
0	56·0	55·6	55·6	55·5	55·5	55·4	55·7
1	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...
3	...	...	55·6	...	...	...	...
4	...	...	...	...	...	...	...
5	...	...	...	55·2	...	...	...
6	...	...	...	...	...	...	...
7	55·4	...	...	...	...	...	55·7
8	...	...	...	...	55·6	...	...
9	...	...	...	...	...	...	...
10	...	55·1	...	55·0	55·6	55·1	...
12	...		54·8†	...	...	...	...
14	...	...	...	55·0	55·6	...	...
16	55·4†	...	...	...	...	...	...
18		...	...	...	55·6	...	55·7*
20	...	...	...	55·2	55·6	...	...
22	...	...	54·8†	...	...	55·3	...
24	...	...		55·4	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	55·6	...	55·8*
30	...	...	...	55·4		...	
32	...	...	...		...	55·4	...
34	...	...	...	...	...		...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

* Observation made ½ fathom deeper than indicated. † Observation made 1 fathom deeper than indicated.

1887.	CHANNEL.	PLATEAU.		ARRAN BASIN.			
Date	Sept. 21	Sept. 21	Sept. 22	Sept. 22	Sept. 22	Sept. 22	Sept. 22
Position	Sanda, N. by E.	Off Rhuad Point	Campbeltown Loch, off ship-yards	Davaar W.N.W., about 4 miles	Off Davaar	Off Imachar Point	Off Loch Ranza
Hour	15.25–15.48	17.45–17.53	9.15–9.20	11.25–11.35	12.5–12.20	13.35–14.0	15.20–15.33
Wind	S.S.W., 0·5	0	0	0	0	0	0
Weather & Sea	Mist, swell	Mist slightly increasing, slight swell	Mist, smooth	Mist, bright, smooth	Mist, bright, smooth,	Haze, bright, smooth,	Cloudless, bright, haze, smooth
Depth	46	23	9	22	41	75	52
Temp. of Air	55·0 dry 52·5 wet	54·2 dry 51·8 wet	55·5 dry 52·0 wet	55·5 dry 52·0 wet	55·5 dry 52·0 wet	58·0 dry 53·8 wet	58·7 dry 4·7 wet
Fathoms							
0	55·8	54·9	55·2	55·2	55·4	55·7	55·3
1	...	...	...	55·0	...	...	...
2	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	55·9	54·9	...	...	...	...	...
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	.
8	...	...	55·1	...	...	...	...
9	...	...		...	...	...	...
10	...	...	...	55·2†	55·1	54·6	54·2
12	...	55·0	...	...	...	...	...
14	55·9†	...	...	54·3†	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	...	54·1†	55·0	53·5	53·1
22	...	55·1	...		...	...	...
24	55·9†		...	...	54·0†	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	53·3	52·1	52·6†
32	...	...	...	...	...	...	...
34	55·9†	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	52·7	52·2	52·4†
42	...	...	...	...		...	...
44	55·9†	...	...	...	...	...	...
46		...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	51·7	51·1
52	...	...	...	...	...	...	
54	...	...	...	...	...	51·6	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	51·5	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	51·4	...
76	...	...	...	...	...		...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	ARRAN BASIN.						
Date	Sept. 22	Sept. 22	Sept. 23	Sept. 23	Sept. 23	Sept. 23	Sept. 23
Position	Inchmarnock Water	Skate Island	Laggan Bay, close inshore	Laggan Bay	Off Laggan Bay	Off Laggan Bay	Off Laggan Bay
Hour	16.14–16.39	17.25–18.0	8.55–9.3	9.7–9.12	9.14–9.20	9.23–9.38	9.40–10.3
Wind	W.S.W., 0·5	W., 2	0	N., 0·5	N., 0·5	N., 0·5	N.E., 0·5
Weather & Sea	Cloudless, bright, slight haze, smooth	Bright, clear, smooth	Mist, thick, smooth	Mist, clearing overhead, smooth	Mist, clearing overhead, smooth	Mist, clearing overhead, smooth	Mist breaking, sun gleaming more strongly, smooth
Depth	87	104	9	22	31	70	102
Temp. of Air	58·7 dry 54·7 wet	55·0 dry 51·3 wet	48·9 dry 49·2 wet	48·9 dry 49·2 wet	48·9 dry 49·2 wet	48·9 dry 49·2 wet	49·2 dry 49·3 wet
Fathoms							
0	54·8	54·2	53·4	54·0	54·1	54·1	54·0
1	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...
3	...	...	53·3	...	...	...	...
4	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	53·3	...	...	...	...
9	...	...		...	...	...	...
10	55·2	53·8	...	53·4†	53·6	...	...
12	...	...	...	...	...	...	...
14	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	54·7	53·3	...	53·0†	53·2	53·2	53·2
22	...	...	...		...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	53·1	53·0	...	...	52·5	52·8	...
32	...	...	...	...		...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	52·4	52·2	...	...	...	51·8	52·3
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	51·8	50·7	...	...	...	...	50·3
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	50·0†	...
60	50·1	...	...	...	...	...	50·2
62	...	50·0†	...	...	...	...	...
64	...	...	...	...	...	...	...
66	49·3	...	...	...	...	...	...
68	...	...	...	...	...	49·2†	...
70	...	49·3	...	...	...		49·3
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	49·3	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	49·2†
82	...	49·3†	...	...	...	...	...
84	...	...	...	...	...	...	...
86	48·5	...	...	...	...	...	...
88		...	...	...	...	...	...
90	...	49·3	...	...	...	...	49·3†
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	49·1	...	...	...	...	49·0†
102	...	49·1†	...	...	...	...	
104	...		...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	ARRAN BASIN.			LOCH FYNE.			
Date . .	Sept. 23	Sept. 23	Sept. 23	Sept. 23	Sept. 23	Sept. 23	Sept. 23
Position .	Towards Skate Island	Skate Bay, close inshore	Off Kilfinnan Bay	Otter Beacon	Gortans	Paddy Rock	Furnace
Hour . .	10.8–10.15	10.29–10.35	12.14–12.34	13.15–13.26	13.53–14.7	14.40–14.47	15.10–15.35
Wind . .	0	Northerly, 0·5	0	0	0	W., 1	W., 0·5
Weather & Sea . .	Mist thicker, sun gleaming, smooth	Misty, bright, smooth	Less mist, bright, smooth	Haze, bright, smooth,	Dull, haze, smooth	Dull, haze, smooth	Dull, smooth
Depth .	34	9	77	30	35	16	35
Temp. of Air . .	49·2 dry 49·3 wet	49·2 dry 49·3 wet	52·0 dry 51·0 wet	52·0 dry 51·0 wet	57·2 dry 53·7 wet	57·2 dry 53·7 wet	58·0 dry 54·3 wet
Fathoms							
0	53·9	54·7	54·7	54·3	54·2	53·5	54·6
1	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...
3	...	55·0	...	...	...	...	53·5
4	...	54·4	...	...	...	...	...
5	...	...	...	...	...	53·2	...
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	54·1	...	...	...	...	...
9	...		...	53·2	...	...	...
10	...	...	53·2	53·4	53·4	...	52·1
12	53·8†	...	...	...	...	...	...
14	...	...	...	...	53·0	52·3	52·2
16	...	...	...	...	...		...
18	...	...	...	53·6†	...	...	...
20	...	...	52·8	52·7	...	...	...
22	53·3†	...	...	...	...	...	...
24	...	...	...	...	53·2	...	52·6
26	...	...	...	...	52·4‖	...	52·1†
28	...	...	...	52·3†	...	...	...
30	...	...	...		...	...	...
32	52·7†	...	...	...	...	...	51·9
34		...	52·0†	...	52·3	...	48·1
36	...	...	...	...		...	47·5‖
38	...	...	...	...	...	...	
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	51·6†	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	50·0	...	...	...	...
58	...	...		...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	LOCH FYNE.				ARRAN BASIN.	KYLES OF BUTE.	
Date	Sept. 23	Sept. 23	Sept. 23	Sept. 23	Sept. 24	Sept. 24	Sept. 24
Position	Strachur	Inveraray	Dunderave	Cuill	Off Ardlamont Point	Angle of Kyles	Ormidale, Loch Ridun
Hour	16.10–16.45	17.13–17.37	17.56–18.10	18.35–18.45	13.37–13.46	14.37–14.45	14.57–15.7
Wind	W., 1·5	S.W., 1–2	W., 1	0	S., 1	S.W., 0·5	0
Weather & Sea	Haze, bright, smooth	Haze, bright, smooth	Slight haze, smooth	Dull, haze, smooth	Bright, haze, smooth	Bright, smooth	Bright, haze, smooth
Depth	74	64	36	15	21	27	12
Temp. of Air	58·0 dry 54·3 wet	58·0 dry 54·3 wet	55·5 dry 53·0 wet	55·5 dry 53·0 wet	57·7 dry 55·0 wet	59·0 dry 55·6 wet	59·0 dry 55·6 wet
Fathoms							
0	55·0	55·0	55·7	56·4	56·5	55·5	56·1
1	...	...	...	...	...	...	...
2	...	...	53·3	54·7	...	...	...
3	53·2	53·2	...	...	...	...	...
4	...	...	...	52·9	...	...	...
5	...	...	52·5	...	54·9	54·2	...
6	...	...	...	...	...	...	54·3
7	52·3	52·3	...	...	...	...	...
8	...	...	...	...	...	..	...
9	...	...	...	...	...	...	...
10	52·1	52·0	52·0	...	54·3	...	54·1†
12	...	...	...	...	...	...	
14	...	...	...	52·0	...	...	...
16	...	...	...		...	54·0	...
18	...	...	...	...	...	...	...
20	51·5	51·2	51·1	...	53·6	...	...
22	...	...	...	...		...	...
24	...	...	50·3†	...	...	...	...
26	...	...	...	...	...	53·9	...
28	...	...	...	...	...		...
30	50·1	49·2	49·1	...	...	...	...
32	49·0†	...	...	...	...	...	...
34	...	48·0†	47·7†	...	...	...	...
36	48·1†	...		...	...	...	...
38	...	...	...	...	...	...	...
40	47·5	47·1	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	46·3	...	...	...	...	...	...
52	...	46·0†	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	45·6†	45·4†	...	...	...	...	...
64	...		...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	45·3†	...	...	...	...	...	...
74		...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	KYLES OF BUTE.	DUNOON BASIN.		KYLES OF BUTE.	LOCH STRIVEN.		HOLY LOCH.
Date	Sept. 24	Sept. 28	Sept. 28	Sept. 28	Sept. 28	Sept. 28	Sept. 29
Position	Strone Cotes	Knock Hill	Knock Hill	Bogany	Off Clapochlar Point	Head	Off Kilmun
Hour	15.50–15.57	12.50–13.0	13.15–13.20	13.53–14.8	15.13–15.37	...	7.56–8.8
Wind	S.W., 0·5	N., 2–3	N., 2–3	N.E., 2	N.E., 1	...	E. by S., 4–6
Weather & Sea	Haze, bright, smooth	Smooth	Smooth	Bright, smooth	Bright	...	Rain, squally, smooth
Depth	20	42	16	27	33	11	13
Temp. of Air	59·0 dry 55·6 wet	50·3 dry 45·0 wet	50·3 dry 45·0 wet	51·38 dry 44·7 wet	... ...	... ...	52·0 dry 50·0 wet
Fathoms							
0	56·0	54·4	53·9	53·7	53·1	54·5	53·0
1	...	...	...	...	53·1	...	...
2	...	...	54·0	...	...	54·1	53·9
3	...	...	...	53·6	54·1	...	...
4	...	...	...	...	...	...	...
5	...	54·7	54·3	...	54·0	53·7	...
6	...	...	...	...	...		...
7	...	...	...	...	...	...	54·0
8	...	...	...	...	...	...	...
9	54·1	...	...	...	...	...	...
10	...	54·7	...	54·1†	...	...	...
12	...	...	...	...	53·9	...	53·7
14	53·1	...	54·1†	...	...	...	
16	...	...		53·9	...	...	...
18	52·7†	...	...	...	...	...	...
20		54·2†	...	53·6	52·7†	...	...
22	...	...	...	53·4†	...	...	...
24	...	...	...	...	52·0	...	...
26	...	...	...	51·7†	...	...	...
28	...	...	...		50·2	...	...
30	...	54·1	...	...	49·7	...	...
32	...	...	...	...	49·4	...	...
34	...	...	...	...		...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	54·1†	...	...	...	...	...
42	...		...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	DUNOON BASIN.					LOCH GOIL.	
Date	Sept. 29	Sept. 29	Sept. 29	Sept. 29	Sept. 29	Sept. 29	Sept. 29
Position	Gantock Beacon	Off Strone Point	Between Coulport and Ardentinny	Dog Rock	Dog Rock	Head	Stuckbeg
Hour	8.50–9.15	9.56–10.15	10.50–11.4	11.40–12.0	12.10–12.15	12.55–13.5	13.23–13.43
Wind	N.N.E., 6	N.E., 2–5	E.N.E., 6	N.E., 4–5	...	E.N.E., 5	E.N.E., 5
Weather & Sea	Bright, rough	Rain	Bright, smooth	Bright, smooth	...	Rain, smooth	Rain, smooth
Depth	41	35	41	50	11	17	45
Temp. of Air	52·0 dry 50·0 wet	53·0 dry 50·8 wet	57·0 dry 51·3 wet	...	...	56·7 dry 50·4 wet	56·7 dry 50·4 wet
Fathoms							
0	53·6	53·3	54·0	54·0	53·6	54·9	54·3
1	...	...	...	...	...	...	...
2	53·8	...	...	...	...	...	...
3	...	...	...	...	...	...	...
4	...	53·3	54·0	...	...	...	...
5	...	...	...	53·1	...	...	...
6	...	...	...	...	...	54·3	...
7	...	...	...	...	...	...	53·3
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	54·0	...	53·7	...	53·1	53·4	...
12	...	53·6	...	...		...	...
14	...	...	...	...	...	...	52·3
16	...	...	...	...	...	52·8	51·1†
18	...	...	...	53·3	...		50·1†
20	54·0	54·0	53·8	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	49·2
26	...	...	...	...	...	...	...
28	...	...	...	53·3†	...	...	...
30	54·0	...	53·7	...	...	...	...
32	...	54·0	...	...	...	...	...
34	54·0†		...	...	...	...	48·1
36	...	...	...	...	...	...	...
38	...	...	...	53·2	...	...	...
40	54·1	...	53·4	...	...	...	...
42		...		...	...	...	...
44	...	...	...	...	...	...	47·5
46	...	...	...	...	...	...	
48	...	...	...	53·1†	...	...	...
50	...	...	...		...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH GOIL.	LOCH LONG.		GARELOCH.			LOCH FYNE.
Date . .	Sept. 29	Sept. 29	Sept. 29	Sept. 30	Sept. 30	Sept. 30	Nov. 5
Position .	Carrick Castle	Thornbank	Arrochar	Row II.	Shandon	Head	Head
Hour . .	14.0–14.11	15.6–15.24	15.58–16.4	7.35–7.42	8.1–8.13	8.30–8.35	13.30
Wind . .	N.W., 2	N.E., 1–2	N.E., 1–2	N.N.E., 1	N.N.E., 1	N.E., 1	N.W., 0·5
Weather & Sea . .	Bright	Bright, smooth	Bright, smooth	Bright, smooth	Bright, smooth	Bright, clear, smooth	Overcast, smooth
Depth .	24	31	11	21	22	10	16
Temp. of Air . .	...	55·5 dry 51·0 wet	55·5 dry 51·0 wet	56·3 dry 49·7 wet	56·3 dry 49·7 wet	56·3 dry 49·7 wet	...
Fathoms							
0	53·4	54·3	54·0	53·7	53·6	54·1	46·0
1	...	...	...	...	...	...	46·4
2	...	...	...	...	...	54·1	...
3	...	...	...	...	...	...	49·5
4	...	...	...	...	...	54·6	...
5	...	...	...	53·9	54·3	...	49·8
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	52·9	...	...	...	...	...	...
9	...	...	...	...	...	54·4	...
10	...	53·0	52·9	54·0	54·2		50·1
12	51·4†	...		...	...	...	...
14	49·7†	...	...	...	...	...	50·1†
16	...	...	...	...	...	...	
18	49·1	...	...	...	...	...	...
20	...	53·0	...	53·9	54·1†	...	...
22	48·2†	53·1	...			...	...
24		...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	52·3	...	...	...	...	...
30	...	51·7	...	...	...	...	...
32	...		...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH FYNE.						
Date . .	Nov. 5	Nov. 5	Nov. 5	Nov. 7	Nov. 7	Nov. 7	Nov. 8
Position .	Off Dunderave	Off Inveraray	Off Strachur	Head	Off Dunderave	Off Strachur	Off Strachur
Hour . .	14.10	15.0	16.10	14.10	15.10	16.30	12.10
Wind . .	0	Northerly 0·5	0	N.E., 4	N.E., 4	N.E., 4	E.S.E., 2
Weather & Sea .	Overcast, smooth	Overcast, smooth	Overcast, smooth	Overcast, sunshine occasionally, rough	Overcast, rough	Overcast, rain, rough	Overcast, rippled
Depth .	33	55	74	16	34	74	6
Temp. of Air	47·8	47·0	46·5	...	49·2	...	...
Fathoms							
0	45·9	45·8	45·9	49·7	49·8	49·8	49·8
1	46·3	46·9	46·4	49·8	49·8	49·8	49·6
2	49·1	48·3	47·6	49·6	49·7	49·8	49·7
3	49·5	49·3	47·2	49·7	49·9	49·9	49·8
4	...	...	...	...	...	...	49·6
5	49·8	49·9	49·6	49·7	49·7	...	49·7
6	...	...	...	49·7	...	...	
7	...	50·1	...	...	...	...	...
8	...	...	...	49·6	...	...	...
9	50·2	...	...	...	...	...	...
10	...	50·0	50·0	49·6	49·9	49·8	...
12	50·2	...	...	49·7‖	49·9†	...	...
14	...	...	...	49·5‖	49·8†	...	...
16	50·2†	...	...	49·5‖	...	...	...
18	...	...	...		...	...	...
20	...	50·1	49·9	...	49·6	49·9	...
22	50·1	...	...	...	49·5†	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	49·8	49·6	...	49·2	...	...
32	49·2	...	...	...	49·2†	49·6†	...
34		49·7	...	...		...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	49·0	...	...	...	...
42	...	...	...	...	...	...	...
44	...	48·0	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	46·8†	...	...	46·9†	...
54	...	46·3	...	...	...	...	...
56	...		...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	45·8†	...	...	...	...
64	...	...		...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	45·6†	...
74	...	...	...	...	...		...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated, ‖ Observation made 1 fathom less deep than indicated.

1887.	GARELOCH.				LOCH LONG.		LOCH GOIL.
Date . .	Nov. 29	Nov. 29	Nov. 29	Nov. 29	Nov. 29	Nov. 29	Nov. 30
Position .	Head	Off Shandon	Above Narrows	Row I.	Thornbank	Head	Head
Hour . .	9.30	10.0	10.40	10.55	13.30	14.25	8.30
Wind .	N.E., 0·5	0	N.E., 0·5	N.E., 0·5	0	N.E., 0.5	Northerly light
Weather & Sea . .	Dull, smooth	Overcast, smooth	Dull, hazy, smooth	Dull, hazy, smooth	Hazy, smooth	Hazy, smooth	Overcast, smooth
Depth .	10	23	21	12	33	10	14
Temp. of Air	39·8	...	40·0	39·2	42·0	41·2	35·5
Fathoms							
0	43·9	43·9	44·8	43·5	44·1	44·9	44·8
1	...	...	...	46·5	...	45·1	46·4
2	...	46·0	...	...	46·1	46·1	...
3	...	...	...	47·5	...	46·3	47·8
4	44·4	...	...	...	...	47·4	...
5	...	...	...	48·0	48·0	...	48·1
6	...	...	...	48·2	...	...	...
7	...	46·8	...	...	...	...	...
8	...	...	...	...	...	...	48·5
9	46·6	...	...	...	...	47·7	...
10		...	47·0	48·3†	...		...
12	...	47·1	...		48·5	...	49·2†
14	...	...	...	...	...	...	
16	...	47·3	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	47·3†	...	...	...	...
22	...	47·5		...	49·3	...	...
24	...		...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	49·5	...	...
34	...	...	...	...		...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	LOCH GOIL.		DUNOON BASIN.			HOLY LOCH.	DUNOON BASIN.
Date	Nov. 30	Nov. 30	Nov. 30	Nov. 30	Nov. 30	Nov. 30	Nov. 30
Position	Off Struckbeg	Off Corryn	Dog Rock	Off Coulport	Stone Point	Off Kilmun	Off Dunoon
Hour	9.10	10.0	10.30	11·30	12.30	13.10	14.25
Wind	N.W., 0·5	S.E., 0·5	S.E., 1	S.S.W., 2·5	S.W., 4	S.W., 4	S.W., 3
Weather & Sea	Overcast, smooth	Dull, rain, smooth	Dull, rain, smooth	Dull, rain, squalls, ripple	Overcast, rough	Dull, rain, smooth	Dull, rough
Depth	45	11	50	35	33	14	52
Temp. of Air	37·0	40·1	40·0	42·0	44·8	45·5	49·0
Fathoms							
0	44·9	42·5	42·5	42·8	45·0	44·2	47·2
1	45·8	45·1	45·0	42·9	...	46·6	47·2
2	45·8	46·3	...	47·2	...	47·6	...
3	45·8	...	48·0	47·6	...	47·9	47·4
4	47·9	...	...	...	...	...	...
5	48·1	47·8	48·5	48·3	48·4	...	48·3
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	48·3	...	...	...	48·5	...
9	...	...	...	...	...	...	...
10	49·0	49·2	49·2	49·0	49·0	...	48·4
12	...		...	...	49·0	49·1†	...
14	...	...	...	49·0	...		...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	50·0	...	49·1	...	...	...	48·4
22	...	...	...	...	48·7	...	...
24	49·9	...	...	49·2	...	...	...
26	...	...	...	...	...	...	...
28	...	...	49·3†	...	...	...	...
30	...	...	...	...	...	...	48·5†
32	...	...	...	...	48·9	...	...
34	49·6	...	...	49·3		...	...
36	...	...	...		...	...	...
38	...	...	49·6†	...	...	...	...
40	...	...	...	...	...	...	48·3†
42	...	...	...	...	...	...	...
44	49·4	...	...	...	...	...	...
46		...	...	...	...	...	...
48	...	...	49·4†	...	...	...	...
50	...	...		...	...	...	48·2†
52	...	...	...	...	...	...	
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	ARRAN BASIN.	KYLES OF BUTE.	LOCH STRIVEN.		KYLES OF BUTE.		
Date	Dec. 2	Dec. 2	Dec. 2	Dec. 2	Dec. 2	Dec. 3	Dec. 3
Position	Off Garroch Head	ogany	Head	Off Clapochlar	Off Strone Cotes	Head of Loch Ridun	Mouth of Loch Ridun
Hour	9.30	11.25	14.25	14.50	15.50	8.10	8.30
Wind	W. by N., 5	W. by N., 6	W. by N., 5	W. by N., 5	W. by N., 6	W.N.W., 5	W. by S., 5
Weather & Sea	Overcast, very rough	Overcast, showers, moderately calm	Dull, rain, smooth	Dull, rain, smooth	Dull, showers, roughish	Overcast, smooth	Dull, rain, smooth
Depth	61	28	11	35	19	11	29
Temp. of Air	45·5	47·8	0·5	50·0	48·5	50·5	50·5
Fathoms							
0	48·0	48·0	48·1	48·9	49·0	47·8	48·0
1	...	...	49·3	48·9	...	...	...
2	...	48·1	49·8	...	...	...	48·9
3	48·1	...	49·8	49·1	...	...	...
4	...	...	...	...	...	...	...
5	48·1	48·1	50·0	49·1	...	48·6	49·1
6	...	...	...	...	...	...	...
7	...	48·3	...	...	...	...	...
8	...	...	...	49·2	49·0	...	49·0
9	...	...	...	...	...	...	...
10	48·3	...	50·1	49·6	...	48·8	...
12	...	...	...	...	...	...	...
14	...	...	...	50·1	...	...	...
16	...	48·7†	...	...	...	...	...
18	...	...	...	...	49·3	...	49·4
20	48·6	...	...	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	50·0	...	...	...
26	...	48·6†	...	...	...	...	...
28	...	...	...	...	...	...	49·3
30	48·4	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	50·1	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	48·6	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	48·4	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	48·3	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1887.	KYLES OF BUTE.	ARRAN BASIN.		PLATEAU.	ARRAN BASIN.		PLATEAU.
Date . .	Dec. 3	Dec. 5	Dec. 5	Dec. 8	Dec. 9	Dec. 9	Dec. 10
Position .	Off Ardlamont Point	Off Loch Ranza	Between Imacher & Carradale	5 miles S. of Sanda	Between Imacher & Carradale	Off Ross Island	Bet. Davaar & Pladda
Hour .	9.50	10.30	12.45	11.0	11.45	14.20	8.45
Wind .	W.S.W., 6	S.W. by W., 6	S.W., 4	S., 4, freshening	N. by E., 3	N. by E., 2	Southerly, 0·5
Weather & Sea .	Overcast, very rough	Overcast, rough	Overcast, sunshine at times, very rough	Overcast, very rough	Sunshine at times, southerly swell	Overcast at times, rough	Overcast, snow showers, smooth
Depth	25	35	77	50	77	43	23
Temp. of Air.	51·0	45·0	47·0	44·5	44·0	42·5	37·0
Fathoms							
0	48·9	48·3	48·8	49·0	47·8	48·0	47·9
1	48·9	...	...	...	...	...	...
2	48·9	48·3	48·8	49·8	47·9	...	47·9
3	...	48·3	...	...	...	...	...
4	48·9	...	48·6	...	...	...	...
5	...	48·3	48·7	49·9	47·8	48·1	...
6	...	...	...	...	...	...	47·9
7	...	...	...	...	47·8	...	...
8	...	48·2	48·7	...	...	...	...
9	...	...	48·7	...	...	...	...
10	...	48·2	48·6	49·8	47·8	48·1	...
12	...	...	48·8‖	...	47·9	...	47·9
14	48·9	48·3	48·6‖	49·8†	47·8†	...	...
16	...	48·3	...	...	...	...	48·0†
18	...	...	...	...	...	...	...
20	...	48·3	48·8	49·9	47·9	...	...
22	...	...	...	...	...	48·0	48·0
24	49·0	48·3	...	...	47·9†	...	
26		...	...	...	...	...	...
28	...	...	...	49·9†	...	...	...
30	...	48·6	48·8	...	48·0	...	...
32	...	...	...	...	...	48·1	...
34	...	48·6	...	...	...	...	...
36	...		...	...	...	...	...
38	...	...	...	49·9†	...	...	...
40	...	...	48·8	...	47·8	...	...
42	...	...	...	...	...	48·1	...
44	...	...	...	...	...		...
46	...	...	...	...	...	...	...
48	...	...	...	49·9†	...	...	...
50	...	...	48·8		48·0	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	48·9	...	48·0	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	48·8	...	48·1	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72		...	...	...	...	...	...
74		...	...	...	...	...	...
76		...	48·9	...	48·1	...	...
78		...		...		...	...
80	A gale has been blowing for three days, and still continues.	...	...	...	A gale blew from 9 o'clock yesterday till dark from the south, then it suddenly veered to N.W., and blew very strong till 5 o'clock this morning, and since then the direction has been N. by E., and force about 3.	...	...
82		...	...	...		...	...
84		...	...	...		...	...
86		...	...	...		...	...
88		...	...	...		...	...
90		...	...	...		...	...
92		...	...	...		...	...
94		...	...	...		...	...
96		...	...	...		...	...
98		...	...	...		...	...
100		...	...	...		...	...
102		...	...	...		...	...
104		...	...	...		...	...
106		...	...	...		...	...
108		...	...	...		...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	PLATEAU.	ARRAN BASIN.		KYLES OF BUTE.	ARRAN BASIN.		LOCH FYNE.
Date	Dec. 10	Dec. 10	Dec. 10	Dec. 15	Dec. 15	Dec. 16	Dec. 16
Position	3½ miles S.W. of Pladda	Off Largybeg Point	Off Brodick	Bogany	Off Garroch Head	Off Kilfinnan Bay	Otter Beacon
Hour	11.15	12.40	15.10	14.45	16.20	13.40	14.45
Wind	S., 0·5	S.W., 1, freshening	N.W., 2	0	S.W., 1	W., 6	N., 0·5
Weather & Sea	Bright, smooth	Bright, ripple	Smooth, showers, roughish	Overcast, hazy, smooth	Overcast, comparatively smooth	Overcast, rain, rough	Overcast, rain, comparatively smooth
Depth	24	66	81	28	61	83	24
Temp. of Air	41·7	42·0	...	...	...	...	...
Fathoms							
0	47·7	47·9	46·0	44·9	45·8	46·5	46·3
1	...	...	...	45·0	...	...	...
2	...	...	46·2	45·1	45·6	...	46·3
3	47·7	...	...	...	...	...	...
4	...	...	...	45·0	...	...	...
5	...	47·9	47·1	45·2	46·1	...	...
6	...	...	...	45·1	...	...	...
7	...	...	...	45·5	...	...	46·5
8	47·6	...	...	46·3	...	...	...
9	...	...	...	...	...	...	...
10	...	...	47·4	46·9	46·0	46·3	...
12	47·6†	...	...	46·8	...	...	46·8
14	...	48·1†	47·6†	47·3	...	...	...
16	...	...	...	47·3‖	...	...	47·0†
18	47·7	...	...	47·6‖	...	...	...
20	...	48·0	47·4	48·0	46·1	46·3	...
22	47·7†	...	...	...	...	47·0	47·2
24		...	...	...	...	47·5	
26	...	...	...	48·3†	...	48·0	...
28	...	...	...		...	...	...
30	...	48·0	47·6	...	46·7	48·3	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	48·0	47·5	...	47·1	48·5	...
42	...	...	...	...	...	..	Here the wind lulled and shifted to the south during the observations.
44	...	48·0†	...	...	...	...	
46	...	...	...	...	...	...	
48	...	...	...	...	...	...	
50	...	...	47·6	...	47·4	48·9	
52	...	...	...	...	...	...	
54	...	48·1†	...	...	...	...	
56	...	...	...	...	...	...	
58	...	...	...	...	...	...	
60	...	...	47·8	..	47·3	...	
62	...	...	...	...		48·9	
64	...	48·1†	...	...	...	...	
66	...		...	...	...	...	
68	...	...	...	...	...	...	
70	...	...	48·3	...	...	...	
72	...	...	...	...	..	49·0	
74	...	...	...	...	...	...	
76	...	...	...	...	...	...	
78	...	...	...	...	...	...	
80	...	...	48·6	...	...	...	
82	...	...		...	...	49·1	
84	...	...	...	...	...		
86	...	...	...	...	...	...	
88	...	...	...	...	...	...	
90	...	...	...	...	...	...	
92	...	...	...	...	...	...	
64	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	..	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	LOCH FYNE.						ARRAN BASIN.
Date	Dec. 16	Dec. 16	Dec. 17	Dec. 17	Dec. 17	Dec. 17	Dec. 18
Position	Gortans	Furnace	Cuill	Dunderave	Off Inveraray	Strachur	Skate Island
Hour	15.35	16.45	8.30	9.40	10.40	12.0	10.30
Wind	S.S.W., 1	W., 1	W., very heavy gale	W., very heavy gale	N.W., very heavy gale	N.W., 6	N.W., 3–6, squalls
Weather & Sea	Rain, smooth	Rain, smooth	Rain and hail, rough	Overcast, hail, rough	Showers rain, rough	Hail shower, rough	Snow showers, rough
Depth	34	38	15	36	65	74	107
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	47·0	46·0	37·8	42·9	43·6	44·5	46·7
1	...	...	38·1	43·0	...	...	...
2	...	46·2	42·4	43·1	43·7	44·6	46·8
3	...	...	42·8	43·4	44·3	...	...
4	...	...	43·0	...	45·1	...	46·7
5	47·3	46·8	...	44·4	45·3	46·1	...
6	...	...	43·9	45·1	...	...	47·0
7	...	...	44·6	45·5	46·1	46·2	...
8	...	...	...	...	...	...	...
9	...	...	46·1	46·2	...	...	...
10	47·3	47·8	47·4	46·6	46·3	46·5	47·3
12	47·0†	48·1†	47·8	{ 46·7‖ 47·2 }	47·2†	47·0	...
14	...	48·1†	47·9	47·8	48·0†	47·3†	...
16	...	48·2†		48·0‖	...	...	...
18	...	...	...	...	48·1	48·1	...
20	...	...	...	...	48·3	48·2	47·3
22	47·3†	...	...	...	...	...	...
24	...	...	...	48·3†	...	48·3†	47·4†
26	...	48·4†		...	...	...	...
28	...	...		...	...	...	...
30	...	...		...	48·3	...	...
32	47·9†	...		...	...	...	47·3
34		...		48·1†	...	48·4†	47·4†
36	...	48·3†			...	...	...
38	...			...	...	...	...
40	...	...		...	48·3	...	47·4
42	...	...			...	...	...
44	...	...			48·3	48·4†	47·6†
46	...	...			...	...	...
48	...	...			...	...	47·7
50	...	...			...	...	...
52	...	...			...	47·8†	...
54	...	...			47·6	...	48·0†
56	...	...			...	...	...
58	...	...			...	...	...
60	...	...			...	...	...
62	...	...			...	47·2†	...
64	...	...			46·9	...	47·9†
66	...	...				...	...
68	...	...				...	...
70	...	...				...	...
72	...	...				46·1†	...
74	...	...					48·0†
76	...	...					...
78	...	...					...
80	...	...					...
82	...	...					...
84	...	...					...
86	...	...					48·2
88	...	...					...
90	...	...					...
92	...	...					...
94	...	...					...
96	...	...					48·3
98	...	...					...
100	...	...					...
102	...	...	...				...
104	...	...	...				...
106	...	...	...	...			48·4
108	...	...	...	...			
Remarks			Water very brown in colour, and quite fresh to taste. A very heavy gale blew all last night from the west, and at times N.W. with rain and hail showers.	Very heavy gale from the west, with a nasty sea, rain and hail showers alternately.	N.W. gale very heavy. Rain and hail showers alternately.	Gale moderating a little, showers still keep up.	

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	KYLES OF BUTE.	ARRAN BASIN.	PLATEAU.	ARRAN BASIN.			
Date	Dec. 19	Dec. 19	Dec. 22	Dec. 23	Dec. 24	Dec. 26	Dec. 27
Position	Bogany	Off Garroch Head	$3\frac{1}{2}$ miles E.S.E. Davaar Isl.	Off Carradale	Bet. Carradale and Machry Bay	North of Pluck Point	S.E. of Ross Island
Hour	14.45	16.0	11.0	11.45	11.0	11.25	11.45
Wind	N.N.W., 2	N.W., 1	W.S.W., 1	N.N.W., 2	N., 1	0	S.E., 0·5
Weather & Sea	Bright	Clear, comparatively smooth	Overcast, comparatively smooth	Bright, roughish	Bright, smooth	Overcast, smooth	Bright, swell
Depth	27	64	22	65	49	44	37
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	43·9	44·0	44·7	45·0	44·9	45·1	44·3
1	...	44·0	44·7	...	...	..	...
2	44·5	44·0	...	...	44·9	...	...
3	...	44·5	44·5	...	...	...	...
4	44·6	44·6	...	...	44·9	...	...
5	45·3	44·8	44·6	45·1	...	...	45·0
6	...	45·6	...	...	45·1	...	...
7	...	...	...	...	...	...	...
8	46·9	46·1	45·8	...	...	...	...
9	...	...	...	...	...	...	...
10	47·4	46·3	45·8	45·2	45·6	45·3	45·4
12	...	...	45·9	...	...	...	...
14	...	46·4†	...	46·0†	...	...	...
16	47·5	...	45·7	...	...	...	45·5
18	...	...	...	...	...	...	...
20	47·3†	46·3	45·7†	...	46·1	45·7	...
22	...	...		...	...	45·9†	...
24	...	...	...	46·2†	...	...	...
26	47·1	...	...	...	...	...	46·2
28		...	...	...	46·3	...	...
30	...	46·2	...	...	...	...	...
32	...	...	...	...	...	46·2†	...
34	...	...	...	46·3†	...	...	...
36	...	...	...	...	...	...	46·1
38	...	...	...	...	46·3	...	
40	...	...	...	...	...	...	...
42	...	46·5†	...	...	...	46·3†	...
44	...	...	...	46·3	...		...
46	...	...	...	...	...	...	...
48	...	...	...	...	46·2	...	...
50	...	...	...	...		...	...
52	...	46·4†	...	...	...	...	...
54	...	...	...	46·2	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	46·4†	...	...	...	...	...
64	...		..	46·3	...	...	...
66	...	...	...		...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	..	...	...	...	..	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1887.	ARRAN BASIN.		CHANNEL.	PLATEAU.		ARRAN BASIN.	
Date	Dec. 28	Dec. 30	Dec. 31	Dec. 31	Dec. 31	Jan. 1, 1888	Jan. 1, 1888
Position	Bet. Carradale and Imacher	Bet. Torrisdale and Auchingallon	5 miles S.S.W. of Paterson's Rock	1 mile E. of Sheep Island	$1\frac{1}{2}$ miles off Rhuad Point	Loch Ranza	Loch Ranza
Hour	12.15	12.0	13.0	14.55	16.10	12.0	13.40
Wind	N.E., 1	0	W., 3	W., 4	W., 2	S.S.E., 5	S.S.E., 4
Weather & Sea	Bright, roughish	Bright, smooth	Overcast	Overcast, rough	Overcast, rough	Snow, overcast, rough	Overcast, roughish
Depth	80	55	49	21	22	9	9
Temp. of Air	...	...	41·5	...	40·2	37·7	...
Fathoms							
0	44·4	44·1	47·2	45·9	44·6	45·0	45·1
1	...	...	...	...	44·6	...	...
2	44·5	...	...	...	...	44·9	45·2
3	...	44·1	...	...	...	...	...
4	44·3	...	...	...	...	45·1	45·1
5	...	...	...	...	44·4	45 0	45·1
6	44·6	44·7	...	...	...	...	...
7	...	...	...	...	...	44·9	45·2
8	45·2	...	...	...	...	...	...
9	...	...	...	...	...	45·0	45·1
10	45·5	45·0	47·3	46·3	44·5†		
12	45·3†	...	...	...	...	...	...
14	...	45·9†	...	...	44·6†	...	...
16	45·7	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	45·8	45·8	47·3	46·9	44·6†	...	...
22	...	...	...			...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	47·2	...	...	...	...
30	46·0	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	46·0	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	47·3	...	...	...	...
40	46·2	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	46·2	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	47·3	...	...	...	...
50	46·1	...		...	...	...	...
52	...	...	...	...	...	...	...
54	...	46·2	...	...	...	...	...
56	...		Tide was just about the turn, but was running to the west.	...	...	...	...
58	46·2†	...		...	...	...	...
60	...	...		...	...	...	...
62	...	...		...	...	...	...
64	...	...		...	...	...	...
66	...	...		...	...	...	...
68	46·2†	...		...	...	...	...
70	...	...		...	...	...	...
72	...	...		...	...	...	...
74	...	...		...	...	...	...
76	...	...		...	...	...	...
78	46·2†	...		...	...	...	...
80		...		...	...	...	...
82	...	...		...	...	...	...
84	...	...		...	...	...	...
86	...	...		...	...	...	...
88	...	...		...	...	...	...
90	...	...		...	...	...	...
92	...	...		...	...	...	...
94	...	...		...	...	...	...
96	...	...		...	...	...	...
98	...	...		...	...	...	...
100	...	...		...	...	...	...
102	...	...		...	...	...	...
104	...	...		...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.					LOCH FYNE.	
Date	Jan. 1	Jan. 2	Jan. 2	Jan. 2	Jan. 3	Jan. 3	Jan. 3
Position	Loch Ranza	Loch Ranza	Bet. North of Arran & Skipness	Off Skate Island	Off Kilfinnan Bay	Otter Beacon	Gortans
Hour	16.40	8.50	9.35	13.0	11.50	13.0	13.40
Wind	N.E., 1	S.E., 2	E., 3	E., 1	S., 3	S., 3	S., 4
Weather & Sea	Overcast, smooth	Snow, overcast, smooth	Snow, overcast, roughish	Overcast, smooth	Sunshine, cloud, roughish	Overcast, rough	Overcast, rough
Depth	8	7½	66	107	80	24	33
Temp. of Air	...	33·5	35·2	...	...	44·1	...
Fathoms							
0	43·8	44·6	45·0	45·7	46·0	46·0	45·9
1	45·0	44·9	...	...	...	...	...
2	45·1	45·0	...	...	...	...	...
3	...	45·0	...	...	...	46·0	...
4	45·0	...	...	...	...	...	...
5	...	45·0	45·0	45·7	46·0	46·0	45·8
6	45·0	...	...	...	...	...	...
7	...	45·1	...	...	...	...	...
8	45·1		...	...	...	...	...
9		...	...	...	...	...	...
10	...	...	45·1	45·8	46·1	46·1	46·0
12	...	...	...	...	...	46·2†	46·0
14	...	...	...	...	46·5†	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	45·8	46·0	46·8	...	...
22	...	...	...	...	...	46·3†	46·1
24	...	...	...	...	46·9†		...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	46·1	46·3	47·0	...	...
32	...	...	...	...	...	...	46·2
34	...	...	...	...	...	...	
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	46·2	46·4	46·4	...	...
42	...	...	...	...	...	...	...
44	...	...	46·5†	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	46·8	46·6	...	...
52	...	...	...	...	...	...	...
54	...	...	46·4†	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	46·8†	...	...
60	...	...	...	46·8	...	...	...
62	...	...	...	...	...	...	...
64	...	...	46·4†	...	...	...	...
66	...	...		...	...	...	...
68	...	...	...	...	46·8†	...	...
70	...	...	...	46·9	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	47·0†	...	...
80	...	...	...	46·9		...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	46·9	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	46·9	...	...	...
108	...	...	...		...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH FYNE.						
Date	Jan. 3	Jan. 3	Jan. 3	Jan. 3	Jan. 6	Jan. 6	Jan. 6
Position	Off Furnace	Opposite Furnace	Pennimore Point, close to Lee Shore	Inveraray	Inveraray	Off Strachur	Pennimore Point, centre of Loch
Hour	15.0	15.20	15.45	21.20	10.45	12.30	13.5
Wind	S., 4	S., 2	S.W., 3	S.S.W., 4	S., 3	S., 5	S., 4
Weather & Sea	Overcast, rain, roughish	Rain, smooth	Rain, roughish	Rain, rough	Overcast, roughish	Overcast, rain, rough	Overcast, rough
Depth	37	15	15	7	9	9	...
Temp. of Air	...	...	...	...	...	49·1	...
Fathoms							
0	47·0	46·8	47·2	39·6	41·3	46·8	46·5
1	...	...	...	46·6	43·0	...	...
2	...	...	...	47·1	47·0	46·8	...
3	...	...	...	...	...	...	...
4	...	...	...	...	47·0	47·1	47·3
5	47·2	46·6	47·3	47·0	...	...	...
6	...	...	...	47·1	47·0	47·3	...
7	...	...	...	47·1	...	...	...
8	...	...	...		47·0	47·2	...
9	...	...	...	...			...
10	47·2	46·8	47·3	...	...	...	47·3
12	...			...	...	...	
14	...	...	...	...	...	...	...
16	47·3	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...
26	47·2	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	46·6	...	...	...	...	...	...
38		...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

1888.	LOCH FYNE.						
Date	Jan. 6	Jan. 6	Jan. 6	Jan. 6	Jan. 6	Jan. 7	Jan. 7
Position	Pennimore Point, close to Lee Shore	Off Furnace	Opposite Furnace	Off Paddy Rock	Nearer Minard Shore	Inveraray	Strachur
Hour	13.15	13.45	14.0	14.40	14.55	8.15	9.20
Wind	S.W., 3	S., 3	S., 4	S.W., 3	4	W.S.W., 1	W., 3
Weather & Sea	Rain, roughish	Overcast, rough	Overcast, rough	Overcast, rough	Overcast, rough	Rain, smooth	Showers, roughish
Depth	15	37	15	16	40	8	8
Temp. of Air	...	...	...	50·0	...	47·8	...
Fathoms							
0	44·8	46·7	46·7	46·4	46·8	44·0	46·1
1	...	...	...	46·3	...	44·6	46·2
2	...	...	...	...	...	46·0	46·1
3	...	...	...	46·3	...	46·5	46·3
4	...	...	...	...	...	...	...
5	47·3	46·7	46·9	46·4	46·5	46·5	46·8
6	...	...	...	...	...	...	...
7	...	...	...	...	...	47·0	46·9
8	...	...	...	...	...		
9	...	...	...	...	...	...	...
10	47·1	47·3	47·0	46·4	46·6	...	...
12		...		...	...	...	...
14	...	...	...	46·4†	46·8†	...	...
16	...	47·0	...		...	...	...
18	...	...	...	...	...	...	...
20	...	...	...	...	46·5	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	46·6†	...	...
26	...	47·0	...	...	...	...	...
28	...	...	...	...	46·4†	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	46·3	...	...
36	...	47·1	...	...	...	...	...
38	...		...	...	46·2†	...	...
40	...	...	...	...		...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	
60	...	...	...	...	...	...	
62	...	...	...	...	...	...	
64	...	...	...	...	...	...	
66	...	...	...	...	...	...	
68	...	...	...	...	...	...	
70	...	...	...	...	...	...	
72	...	...	...	...	...	...	
74	...	...	...	...	...	...	
76	...	...	...	...	...	...	
78	...	...	...	...	...	...	
80	..	...	...	...	...	...	
82	...	...	...	...	...	...	
84	...	...	...	...	...	...	
86	...	...	...	...	...	...	
88	...	...	...	...	...	...	
90	...	...	...	...	...	...	
92	...	...	...	...	...	...	
94	...	...	...	...	...	...	
96	...	...	...	...	...	...	
98	...	...	...	...	...	...	
100	...	...	...	...	...	...	
102	...	...	...	...	...	...	
104	...	...	...	...	...	...	
106	...	...	...	...	...	...	
108	...	...	...	...	...	...	

Wind was blowing up the Loch, not off the Shore as on previous days.

† Observation made 1 fathom deeper than indicated.

1888.	LOCH FYNE.	ARRAN BASIN.	LOCH STRIVAN.				
Date	Jan. 7	Jan. 7	Jan. 7	Jan. 8	Jan. 8	Jan. 8	Jan. 8
Position	Gortans	Off Skate Island	Off Strone Point.	Head	Off Artaraig Hills	Off Clapochlar Point	Off Strone Point
Hour	11.0	13.25	16.15	9.0	9.40	10.15	11.0
Wind	S.W. by W., 3	W., 2	S., 1	N.W.&N.E. gusts from all directions, 4	Strong gusts	S., 2	S., 1
Weather & Sea	Overcast, rough	Showers rain, mist, rough	Mist and rain, smooth	Rain, mist, smooth	Rain, mist, roughish	Rain, mist, roughish	Rain, mist, smooth
Depth	35	106	36	12	24	37	36
Temp. of Air	48·8	48·2	47·0 (wet)	50.2 (wet)	50·2 (wet)	...	51·1 (wet)
Fathoms							
0	46·4	45·9	44·8	46·0	44·9	44·9	45·6
1	...	...	...	44·3	...	45·0	45·7
2	...	...	...	...	...	...	...
3	...	...	...	44·2	...	44·8	45·3
4	...	...	...	45·2	...	...	...
5	46·3	45·8	45·2	...	45·3	45·3	45·4
6	...	...	...	46·2	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	46·3	...	45·9	46·1
9	...	...	...	46·3	...	...	...
10	46·1	45·8†	46·1	46·3†	46·0	46·0	46·1
12	...	...	...		46·2†	...	...
14	46·0	...	46·1†	...	...	...	46·2†
16	...	...	...	...	...	46·2	...
18	...	...	...	...	46·3	...	...
20	...	45·9	...	...	...	...	...
22	...	...	...	...	46·3†	...	...
24	45·9	...	46·0†	...		...	46·2†
26	...	...	...	...	...	46·3	...
28	...	...	...	...	...	...	...
30	...	45·8	...	...	...	...	...
32	...	...	...	...	...	...	...
34	46·0	...	46·2†	...	...	...	46·4†
36		...		...	...	46·4	
38	...	...	...	...	...		...
40	...	46·0	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...		...	...	...	...
64	...	46·5†		...	...	...	...
66	...	...		...	...	...	...
68	...	...		...	...	...	...
70	...	...		...	...	...	...
72	...	...		...	...	...	...
74	...	...		...	...	...	...
76	...	...		...	...	...	...
78	...	...		...	...	...	...
80	...	...		...	...	...	...
82	...	...		...	...	...	...
84	...	46·6†		...	...	...	...
86	...	...		...	...	...	...
88	...	...		...	...	...	...
90	...	...		...	...	...	...
92	...	...		...	...	...	...
94	...	...		...	...	...	...
96	...	...		...	...	...	...
98	...	...		...	...	...	...
100	...	...		...	...	...	...
102	...	...		...	...	...	...
104	...	46·8†		...	...	...	...
106	...			...	...	...	...
108	...	...		...	...	...	...

The temperature of the air was 52° F. in Loch Strivan at 21·15.

† Observation made 1 fathom deeper than indicated.

1888.	BUTE PLATEAU.		KYLES OF BUTE.	ARRAN BASIN.	PLATEAU.		
Date . .	Jan. 8	Jan. 8	Jan. 8	Jan. 8	Jan. 18	Jan. 18	Jan. 18
Position .	Off Port Lamont	Half way between Rothesay and Lamont Shore	Off Bogany Point	Off Garroch Head	Off Stranraer Head	Off Bennan Head	Mouth of Loch Ryan
Hour . .	11.30	11.50	12.10	13.30	8.5	12.20	15.35
Wind . .	S., 1	S., 2	N.W., 4	S.W., 1	E., 1	E., 1	S., 1
Weather & Sea .	Rain, mist, smooth	Rain, mist, roughish	Rain, mist, rough	Overcast, rough, swell	Overcast, smooth	Bright, smooth	Bright, smooth
Depth .	29	22	27	63	2	11	9
Temp. of Air	...	...	50·2	51·0	34·0	...	...
Fathoms							
0	45·8	45·7	45·5	45·7	40·0	45·0	44·2
1	...	...	...	...	40·1	...	...
2	...	...	...	...	40·4	...	...
3	45·5	...	45·3	...		...	...
4	...	...	...	...	...	...	44·2
5	45·6	...	...	45·4	...	45·0	...
6	...	...	45·5	...	...	...	...
7	...	...	...	...	...	...	...
8	45·8	...	...	...	...	...	44·1
9	...	...	...	...	...	...	
10	...	45·6†	45·6	45·8	...	45·3	...
12	...	...	...	...	...		...
14	...	...	...	45·5†	...	...	...
16	...	...	45·6	...	...	...	...
18	45·9	...	...	...	...	...	...
20	...	46·2†	...	45·3	...	...	...
22	...		...	...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	45·1	...	...	...	...
28	46·3	...		...	...	...	...
30		...	...	45·3	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	45·5	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	45·5	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	45·8	...	...	...
64	...	...	...		...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	PLATEAU.		LOCH RYAN.				LOCH STRIVAN.
Date . .	Jan. 19	Jan. 19	Jan. 19	Jan. 19	Jan. 19	Jan. 20	Jan. 27
Position .	Corsewell Light, S.E. ½ S. 5 miles	Corsewell Light, S. ½ W. 3 miles	Mouth of Loch Ryan	½ mile above Cairn Ryan Lighthouse	Off Stranraer Harbour	Head of Loch Ryan	Head
Hour . .	12.30	14.10	15.0	15.45	16.30	16.0	15.35
Wind . .	S., 2	S.S.E., 2	S.S.E., 3	S.E., 2	S.E., 1	S.S.E., 3	N.N.W., heavy gale
Weather & Sea . .	Overcast, swell (heavy)	Overcast, rough	Overcast, rough	Overcast, roughish	Overcast, smooth	Dense fog, smooth	Cloudy, bright, rough
Depth .	37	14	8	5	3	3	11
Temp. of Air	...	...	...	...	...	...	35·9
Fathoms							
0	45·2	44·9	44·6	42·3	39·8	40·0	45·1
1	...	...	...	...	39·9	39·9	...
2	...	...	...	42·3	39·8	39·9	...
3	...	...	...	...	40·0	40·1	...
4	...	...	44·4	42·3			...
5	45·2	...	...		...	...	45·4
6	...	...	...	...	...	...	...
7	...	44·7	44·4	...	...	...	...
8	...	...		...	...	...	...
9	...	...	...	...	...	...	...
10	45·1	...	...	...	...	...	45·4
12	...	44·9†	...	...	...	...	
14	...		...	...	...	...	...
16	45·1	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...
26	45·4	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	
36	45·9	...	...	...	...	...	On 26th and 27th a strong wind had been blowing down Loch Strivan.
38		...	...	...	...	...	
40	...	...	...	...	...	...	
42	...	...	...	...	...	...	
44	...	...	...	...	...	...	
46	...	...	...	...	...	...	
48	...	...	...	...	...	...	
50	...	...	...	...	...	...	
52	...	...	...	...	...	...	
54	...	...	...	...	...	...	
56	...	...	...	...	...	...	
58	...	...	...	...	...	...	
60	...	...	...	...	...	...	
62	...	...	...	...	...	...	
64	...	...	...	...	...	...	
66	...	...	...	...	...	...	
68	...	...	...	...	...	...	
70	...	...	...	...	...	...	
72	...	...	...	...	...	...	
74	...	...	...	...	...	...	
76	...	...	...	...	...	...	
78	...	...	...	...	...	...	
80	...	...	...	...	...	...	
82	...	...	...	...	...	...	
84	...	...	...	...	...	...	
86	...	...	...	...	...	...	
88	...	...	...	...	...	...	
90	...	...	...	...	...	...	
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observations made 1 fathom deeper than indicated.

1888.	LOCH STRIVAN.	DUNOON BASIN.	ARRAN BASIN.	GARELOCH.			
Date	Jan. 27	Jan. 27	Jan. 30	Feb. 9	Feb. 9	Feb. 9	Feb. 9
Position	Off Clapochlar Point	Off Strone Point	Between Carradale and Imacher	Head	Off Shandon	Above Narrows	Row (I)
Hour	16.30	17.0	11.0	8.20	8.45	9.15	9.40
Wind	N.N.W., heavy gale	N., 5	0	W.N.W., 1–4, squalls	W.N.W., 1–2, squalls	N.W., 1	N.W., 1–3, squalls
Weather & Sea	Partially cloudy, very rough	Clear, rough	Sunshine, calm	Showers rain, smooth	Overcast, smooth	Sunshine, cloudy, smooth	Showers rain, smooth
Depth	34	36	77	11	23	27	12
Temp. of Air	35·0	34·9	44·9	43·5	43·6	45·0	45·9
Fathoms							
0	45·2	45·0	44·7	43·8	43·8	43·8	43·5
1	...	...	...	...	...	...	...
2	...	...	...	...	43·8	...	44·1
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	44·3
5	45·3	45·1	44·6	43·5	...	...	44·5
6	...	...	...	...	...	43·9	...
7	...	...	...	...	43·6	...	...
8	...	...	...	...	...	...	44·7
9	...	...	...	...	...	...	...
10	45·3	45·1	...	43·7	...	43·8	44·8†
12	45·3†	...	...		43·6	...	
14	...	45·1†	44·8†	...	...	...	...
16	...	...	...	...	43·9†	44·1	...
18	...	...	...	...	...	...	...
20	...	...	...	...	...	44·1	...
22	45·6†	...	...	...	44·1	...	...
24	...	45·5†	44·8†	...		...	...
26	...	...	...	...	...	44·3	...
28	...	...	...	...	...		...
30	...	...	...	...	...	...	...
32	45·8†	...	...	...	...	...	...
34		45·6†	44·8†	...	...	...	...
36	...		...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	44·9†	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	44·9†	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	44·8	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	45·0	...	...	...	...
78	...	...		...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH LONG.		DUNOON BASIN.	LOCH GOIL.			DUNOON BASIN.
Date	Feb. 9	Feb. 9	Feb. 9	Feb. 9	Feb. 10	Feb. 10	Feb. 10
Position	Head	Thornbank	Off Dog Rock	Off Stuckbeg	Head	Off Corryn	Off Coulport
Hour	14.15	15.10	16.5	16.50	8.30	10.55	11.40
Wind	W.N.W., 1–3, squalls	W.N.W., 1–3, squalls	W.N.W., 3	W.N.W., 1–3, squalls	W.N.W., 1–4, squalls	W.N.W., 2	N.W., 1–2 squally
Weather & Sea	Showers rain, smooth	Showers rain, smooth	Overcast, roughish	Rain, smooth	Snow, smooth	Snow, smooth	Showers hail, smooth
Depth	11	32	50	45	11	11	37
Temp. of Air	45·2	44·0	43·8	41·0	37·0	38·8	38·6
Fathoms							
0	43·0	44·0	44·1	45·1	44·8	44·7	44·6
1	43·8	...	...	...	45·4	...	44·6
2	43·8	...	...	...	45·5	...	44·5
3	44·4	...	...	...	45·6	...	44·9
4	44·9	...	...	...	...	...	...
5	45·1	45·0	...	45·3	45·8	45·0	44·8
6	...	...	...	...	...	...	...
7	45·2	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	45·2	...	...	...	...	...	...
10	45·2	45·5†	44·9	45·9	46·0	45·1	44·8
12		...	...	...			...
14	...	...	...	46·1†	...	...	...
16	...	...	...	...	...	...	44·8
18	...	45·1	...	...	...	...	...
20	...	45·2†	45·0	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	46·2	...	...	...
26	...	...	...	...	...	...	44·4
28	...	...	45·0†	...	...	...	...
30	...	45·2†	...	...	...	...	...
32	...		...	...	...	...	...
34	...	...	...	46·3	...	...	...
36	...	...	...	...	...	...	44·5
38	...	...	45·1†	...	...	...	
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	46·2	...	...	...
46	...	...	...		...	...	...
48	...	...	45·1†	...	...	...	...
50	...	...		...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	DUNOON BASIN.	HOLY LOCH.		DUNOON BASIN.			
Date . .	Feb. 10	Feb. 10	Feb. 10	Feb. 10	Feb. 10	Feb. 10	Feb. 10
Position .	Off Blairmore	Off Kilmun	Mouth	Bet. Mouth of Holy Loch and Lagan Point	Close to Lagan Point (Lee Shore)	Off Dunoon	Off Knock Hill
Hour . .	12.35	13.30	14.5	14.25	15.0	16.10	17.20
Wind . .	N.W., 2	N.W. 3	N.W. by W., 2	N.W., 2	N.W. by W., 2	N.W. by W., 1	W.N.W., 2
Weather & Sea . .	Snow showers, smooth	Bright sunshine, roughish	Bright, roughish	Bright, roughish	Bright, roughish	Bright, smooth	Snow, rough
Depth .	33	12	15	33	17	50	41
Temp. of Air	33·4	41·0	40·8	40·8	40·0	38·1	33·0
Fathoms							
0	43·8	44·0	44·1	44·1	43·7	44·0	43·8
1	43·9	44·0	44·1	...	...	...	...
2	...	...	44·1	...	43·5	...	...
3	44·2	44·3	...	...	...	...	...
4	...	...	44·3	...	43·9	...	...
5	44·3	...	...	44·3	...	...	44·3
6	...	44·4	...	...	44·0	...	...
7	...	...	...	...	...	...	...
8	44·8	44·8	...	...	...	...	...
9	...	...	44·6	...	...	...	...
10	44·9	44·8†	...	44·7	44·5†	44·3	44·3
12	44·8		...	44·7	...	...	...
14	...	...	44·7	...	...	...	...
16	...	...		...	44·5	...	...
18	...	...	...	...		...	...
20	...	...	...	...	...	44·4	44·2
22	44·4	...	...	44·5	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	44·6†	...
30	...	...	...	...	...	...	44·3
32	44·5	...	...	44·6	...	...	...
34		...	...		...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	44·4†	...
40	...	...	...	...	...	...	44·3
42	...	...	...	...	...	...	
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	44·4†	...
50	...	...	...	...	...		...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.	KYLES OF BUTE.	LOCH STRIVAN.			KYLES OF BUTE.	
Date	Feb. 11	Feb. 11	Feb. 11	Feb. 11	Feb. 11	Feb. 11	Feb. 13
Position	Off Garroch Head	Bogany	Head	Off Clapochlar Point	Off Strone Point	Strone Cotes	Head of Loch Ridun
Hour	10.0	11.40	13.55	14.45	15.30	16.30	10.20
Wind	N., 1	N., 1	N., 1	N.N.W., 1	N.N.W., 1	N.W., 1	N., 0·5
Weather & Sea	Bright, slight swell	Bright, smooth	Bright sunshine, smooth	Bright, smooth	Bright, smooth	Bright, smooth	Snow, smooth
Depth	64	28	11	36	37	19	11
Temp. of Air	34·0	35·2	39·8	38·5	37·2	34·1	34·0
Fathoms							
0	43·8	44·0	44·8	44·6	44·4	44·2	43·8
1	...	...	...	...	...	...	43·9
2	43·8	44·0	45·0	...	44·4	...	44·3
3	...	...	...	...	...	...	44·3
4	...	...	45·1	...	...	...	...
5	44·1	44·3	45·2	44·6	44·3	44·2	44·5
6	...	...	...	...	...	...	...
7	...	44·4	...	...	...	...	...
8	...	...	45·1	...	...	44·3	...
9	...	...	...	...	...	...	...
10	44·2	...	45·1	44·9	44·4	...	44·9
12	...	...		...	...	44·4	
14	...	...	...	44·9	44·4	44·6†	...
16	...	44·4†	...	...	44·8	...	...
18	...	...	...	...	44·7	44·9	...
20	44·3	...	...	...	...		...
22	...	...	...	...	...	...	...
24	...	...	...	44·8†	...	...	...
26	...	44·6†	...	...	44·7	...	...
28	...		...	...	...	...	...
30	44·4	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	44·8†	...	...	...
36	...	...	...		44·7	...	...
38	...	...	...	...		...	...
40	...	...	...	...	...	...	...
42	44·5†	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	44·4†	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	44·5†	...	...	...	...	...	...
64		...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	KYLES OF BUTE.		LOCH FYNE.				
Date . .	Feb. 13	Feb. 13	Feb. 14	Feb. 14	Feb. 14	Feb. 14	Feb. 14
Position .	Mouth of Loch Ridun	Off Ardla-mont Point	Off Kinglass Ho.	Dunderave	Off Inveraray	Off Strachur	Off Furnace
Hour . .	10.50	12.0	8.55	9.30	10.15	13.35	14.50
Wind . .	N.W., 0·5	W.N.W., 2	N., 0·5	N.E., 0·5	0	N., 1	N., 1
Weather & Sea . .	Snow, calm	Bright, roughish	Bright, ice on surface	Bright, smooth	Bright, smooth	Bright, smooth	Bright, smooth
Depth .	27	24	20	34	62	76	36
Temp. of Air	34·5	40·0	30·0	35·0	37·5	40·0	39·5
Fathoms							
0	43·0	43·0	38·5	40·0	42·3	42·0	41·3
1	...	43·0	42·0	42·5	43·0	...	41·3
2	43·7	43·1	44·8	43·3	44·5	44·0	44·4
3	...	43·2	...	45·3	45·6	...	45·0
4	44·2	...	46·4	46·1	46·2	45·2	...
5	...	...	...	46·5	46·4	...	46·1
6	44·2	...	46·6	...	...	46·5	...
7	...	...	...	...	...	...	...
8	...	...	...	...	46·4	46·8	...
9	...	...	...	...	...	46·7	...
10	...	...	46·8	46·9	46·8	46·2	46·4
12	...	44·1†	46·6†	46·8†	46·8	{ 46·8‖ 46·4 }	...
14	...	...	...	...	...	46·5‖	46·2†
16	44·6	...	46·2	46·0	46·2	46·3	...
18	...	...	45·8†	...	...	...	...
20	...	...		45·6	46·0	45·8	...
22	...	44·9†	...	45·6†	...	...	...
24	...		...	...	...	...	45·7†
26	44·9	...	...	...	...	...	...
28		...	...	...	...	...	...
30	...	...	...	...	45·6	45·8	...
32	...	...	...	45·6†	...	...	...
34	...	...	...		...	...	45·2†
36	...	...	...	...	...	...	
38	...	...	...	...	...	...	...
40	...	...	...	...	45·6	45·5	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	45·3†	45·5	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	45·5†	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	45·3†	...	...
62	...	...	...	...		...	...
64	...	...	...	...	...	45·3†	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	45·3†	...
76	...	...	...	...	...		...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated. ‖ Observation made 1 fathom less deep than indicated.

1888.	LOCH FYNE.		ARRAN BASIN.				
Date	Feb. 14	Feb. 14	Feb. 14	Feb. 15	Feb. 15	Feb. 15	Feb. 15
Position	Gortans	Otter Beacon	Off Kilfinnan Bay	Skate Island	Inchmarnock Water	Off Loch Ranza	Between Imacher & Carradale
Hour	16.0	16.45	17.20	9.20	11.10	12.25	14.10
Wind	N., 0·5	N., 0·5	N., 1	N., 1	N., 1	N., 0·5	W., 0·5
Weather & Sea	Clear, smooth	Clear, smooth	Partially overcast, smooth	Clear, smooth	Bright sunshine, roughish	Bright sunshine, smooth	Bright sunshine, smooth
Depth	27	23	60	107	78	59	60
Temp. of Air	37·8	35·5	35·0	34·5	36·1	41·5	42·0
Fathoms							
0	43·7	43·6	43·9	43·7	44·0	44·0	...
1	...	...	...	...	44·0	...	...
2	45·3	44·6	43·7	43·7	...	...	...
3	...	...	...	...	44·1	44·0	...
4	45·2	...	...	...	...	...	...
5	...	44·3	44·1	43·8	44·0	44·1	...
6	45·1	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	44·4	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	...	44·9	44·2	44·1	44·0	...
12	...	44·3	...	44·2	...	...	...
14	...	...	...	44·3†	44·1†	...	...
16	44·8	...	...	...	..	...	...
18	...	...	...	...	...	...	...
20	...	...	44·9	...	...	44·3	...
22	...	44·6	...	...	...	...	...
24	...		...	44·3†	44·4†	...	...
26	45·0	...	...	...	...	...	...
28		...	...	...	...	...	...
30	...	...	45·0	...	...	44·6	...
32	...	...	...	...	...	...	...
34	...	...	...	44·6	44·8†	...	...
36	...	...	...	...	...	...	...
38	...	...	45·0†	...	...	44·8	44·1†
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	44·8†	44·8†	...	...
46	...	...	...	...	...	...	...
48	...	...	44·8†	...	...	44·7	44·3†
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	44·8†	...	...	...
56	...	...	...	...	44·9†	...	...
58	...	...	44·9†	...	...	44·9	44·5†
60	...	...		...	...		
62	...	...	...	...	...	...	...
64	...	...	..	44·8†	...	...	...
66	...	...	...	...	44·9†	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	44·9†	...	...	...
76	...	...	...	...	44·9†	...	...
78	...	...	...	...		...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	44·9	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	44·8	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	44·9	...	...	...
108	...	...	...		...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.						LOCH FYNE.
Date	Feb. 15	Feb. 16	Feb. 17	Feb. 17	Feb. 17	Feb. 17	Feb. 28
Position	Between Imacher and Carradale	Mull of Cantyre, N. ½ W., 8 miles	Between Davaar and Pladda	South of Holy Island	Off Brodick	Garroch Head	Off Strachur
Hour	14.25	13.45	9.40	12.0	14.45	16.25	11.15
Wind	W., 0·5	S., 1	N.E., 6	N.E., 6	N., 5	N., 3	N.E., 2
Weather & Sea	Bright, sunshine, smooth	Bright swell	Clear, very rough	Clear, very heavy	Clear, very rough	Clear, roughish	Sunshine, smooth to ruffle
Depth	80	64	20	59	86	65	75
Temp. of Air	42·1	39·5	42·0	43·0	43·2	42·1	39·3d.–34·0w.
Fathoms							
0	44·1	44·5	43·7	43·0	42·8	43·2	44·8
1	44·1	...	...	...	...	...	...
2	...	...	...	...	...	...	...
3	44·1	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	44·1	44·5	...	43·0	43·0	43·2	44·6
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	44·0	...
9	...	...	43·6	...	...	...	...
10	44·2	44·8	...	43·0	...	44·1	...
12	...	...	...	...	...	...	...
14	44·1†	44·9†	...	...	44·0†	44·1†	44·7†
16	...	...	...	...	...	...	...
18	...	...	43·7†	...	...	...	...
20	...	...		43·1	44·2	...	44·7
22	...	...	...	...	...	...	...
24	44·3†	44·7†	...	...	44·2†	44·3†	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	43·1	...	...	44·5
32	...	...	...	...	...	...	...
34	44·3†	44·9†	...	43·4†	44·7†	44·4†	...
36	...	...	...	...	...	...	...
38	...	...	...	44·1	...	...	...
40	...	...	...	...	...	44·5	44·4
42	...	44·9†	...	...	...	...	...
44	44·4†	...	...	...	44·5†	44·8	...
46	...	...	...	...	...	...	...
48	...	...	...	44·3	...	...	...
50	...	...	...	...	44·6	44·8	...
52	...	44·7†	...	...	...	...	...
54	...	...	...	...	44·8†	44·6	44·5
56	...	...	...	...	...	...	...
58	44·8†	...	...	44·6	...	...	...
60	...	...	...		...	...	...
62	...	44·9†	...	...	...	...	...
64	...		...	...	44·8†	44·9	44·4
66	...	...	...	...	...		...
68	44·7†	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	44·8†	...	44·4
76	...	...	...	...	...	...	
78	44·9†	...	...	...	...	...	...
80		...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	45·0†	...	...
86	...	...	...	...		...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.	LOCH GOIL.		DUNOON BASIN.			
Date	Feb. 28	March 1	March 1	March 1	March 1	March 1	March 1.
Position	Off Skate Island	Head	Off Stuckbeg	Dog Rock	Off Coulport	Gantock	Knock Hill
Hour	15.15	12.35	13.10	14.0	14.55	16.10	17.30
Wind	0	N.E., 1	N.E., 1	N.E., 1	N.E., 1	N.E., 0·5	N.E., 0·5
Weather & Sea	Sunshine, smooth	Bright, smooth	Bright, smooth	Bright, smooth	Bright, smooth	Bright, smooth	Clear, smooth
Depth	106	13	46	51	36	53	35
Temp. of Air	40·5	42·0	41·9	41·1	42·2	43·0	40·1
Fathoms							
0	42·1	44·5	44·3	43·0	43·0	43·5	43·2
1	...	44·3	...	...	...	...	...
2	...	44·9	...	...	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	42·1	44·6	44·3	...	42·9	...	43·2
6	...	...	...	...	...	...	...
7	...	44·3	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	42·2	...	44·1	43·8	43·2	43·8	43·2
12	...	44·3	...	...	...	...	...
14	...		...	...	43·9†	...	43·5
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	42·6	...	...	44·3	...	43·8	...
22	...	...	...	...	...	...	...
24	...	...	44·0†	...	44·3†	...	43·8
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	43·9	...	...	44·3	...	...	...
32	...	...	...	...	...	43·9	...
34	...	...	44·0†	...	44·3†	...	44·1
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	44·3	...	...	...
42	...	...	...	...	...	44·0	...
44	...	...	44·1†	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	44·9	...	...	44·3	...	...	...
52	...	...	...	...	...	44·1	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	44·9†	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	44·9†	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	45·0†	...	...	...	...	...	...
106		...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	PLATEAU.				CHANNEL.	ARRAN BASIN.	
Date	March 6	March 8	March 8	March 10	March 17	March 19	March 20
Position	Sanda, W. by N., 4 miles	Off Mouth of Campbelltown Loch	Off Trench Beacon	Bet. Rhuad Point and Sanda	Off Deas Point, Mull of Cantyre	Off Brown Head, Arran	E. of Ross Island, Kilbrennan Sound
Hour	10.30	10.0	10.50	15.0	11.30	10.15	10.20
Wind	S.W., 2	S.S.W., 2	S.S.W., 3	S.W., 1	S., 1	E., 4–6, squalls	N.E., 3
Weather & Sea	Overcast, rough	Showers rain, very heavy swell	Overcast, smooth	Overcast, heavy swell	Overcast, roughish	Clear, very rough	Bright, rough
Depth	21	22	11	21	50	11	36
Temp. of Air	45·0	46·0	46·8	44·8	36·6	40·0	...
Fathoms							
0	42·3	42·3	42·2	42·7	43·0	41·8	41·9
1	...	42·3	...	...	...	...	...
2	...	...	...	...	...	...	...
3	...	42·3	...	...	...	...	...
4	...	...	...	...	...	...	...
5	...	42·3	42·2	...	...	41·6	41·8
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	42·3	42·2†	42·2	42·6	43·0	41·8	41·9
12	...	...	...	...	...	...	...
14	...	...	...	...	...	...	41·9†
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	42·9	42·2†	...	42·8	43·1	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	41·7†
26	...	...	...	...	...	...	...
28	...	...	...	...	43·0†	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	41·8†
36	...	...	...	...	...	...	...
38	...	...	...	...	43·0†	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	43·1†	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	CHANNEL.	ARRAN BASIN.			LOCH FYNE.		
Date	March 21	March 22	March 22	March 22	March 22	March 22	March 22
Position	Sanda, N.N.E., 6 miles	Off Carradale	Skate Island	Off Kilfinnan Bay	Otter Beacon	Gortans	Furnace
Hour	11.0	9.15	12.30	14.20	15.20	16.0	17.10
Wind	W., 1	W., 1	0	E., 0·5	E., 2	E., 4	E., 0·5
Weather & Sea	Partially overcast, heavy swell	Rain, roughish	Fog, smooth	Rain thick, smooth	Overcast, smooth	Rain, smooth	Overcast, smooth
Depth	63	75	106	79	29	34	35
Temp. of Air	41·9	46·3	46·5	44·5	43·9	42·5	43·8
Fathoms							
0	42·9	41·9	42·8	42·4	42·3	43·0	43·1
1	...	41·8	...	...	...	...	...
2	...	41·9	...	...	42·3	...	...
3	...	...	42·2	...	...	...	...
4	...	...	...	...	...	...	...
5	42·8	41·9	42·1	...	42·7	52·9	43·1
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	42·3	...	42·8	...	...
9	...	...	...	...	...	...	...
10	42·9	42·0	...	42·7	...	42·8	43·1
12	...	...	42·8	...	...	42·8†	...
14	42·9†	42·1†	42·8†	...	...	...	43·0†
16	...	...	...	...	...	...	...
18	...	...	...	...	43·1	...	...
20	...	...	...	43·4	...	...	...
22	...	...	...	...	...	42·9†	...
24	42·9†	42·2†	42·8†	...	...	...	43·3†
26	...	...	...	...	...	...	...
28	...	...	...	...	43·3	...	...
30	...	...	...	43·8		...	...
32	...	...	...	...	...	43·1†	...
34	43·1†	42·5†	43·0†	...	...		44·0†
36	...	...	...	...	...	...	
38	...	...	...	...	...	...	...
40	...	...	...	43·3	...	...	...
42	43·0	...	...	...	...	...	...
44	...	42·8†	43·1†	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	43·3	...	...	...
52	43·3	...	...	...	...	...	...
54	...	42·9	43·2†	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	43·3	...	...	...
60	...	...	...	...	...	...	...
62	43·3	...	...	...	...	...	...
64		43·0	43·2†	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	43·3	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	42·9	43·1†	...	...	...	...
76	...		...	...	...	...	...
78	...	...	...	43·3	...	...	...
80	...	...	...		...	...	...
82	...	...	...	...	...	...	...
84	...	...	43·0†	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	42·9†	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	42·7†	...	...	...	...
106	...	...		...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH FYNE.				ARRAN BASIN.	KYLES OF BUTE.	
Date . .	March 22	March 23	March 23	March 23	March 23	March 23	March 23
Position .	Strachur	Cuill	Dunderave	Off Inveraray	Between Ardlamont Point and Etterick Bay	Mouth of Loch Ridun	Head of Loch Ridun
Hour . .	18.0	9.45	10.15	10.45	18.5	19.20	19.45
Wind . .	E., 0·5	N.E., 4	N.E., 2–4, squalls	N.E., 2–4, squalls	N.E., 3	N., 1	N., 1
Weather & Sea . .	Overcast, smooth	Clear, smooth	Bright, smooth	Bright, smooth	Clear, smooth	Clear, smooth	Overcast a little, smooth
Depth .	75	15	34	63	36	29	11
Temp. of Air	42·0	37·2	37·5	37·7	37·0	...	...
Fathoms							
0	43·4	43·0	42·8	43·1	42·5	42·2	42·5
1	...	...	...	...	...	...	...
2	...	43·2	...	43·2	...	42·4	...
3	...	...	...	...	...	...	...
4	...	43·3	...	...	...	...	...
5	43·1	...	43·2	43·2	42·4	42·9	43·1
6	...	43·3	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	43·0	...
9	...	43·3	...	...	...	...	...
10	43·1	...	43·1	43·3	42·3	...	43·1
12	...	...	43·1	...	...	...	
14	...	43·3	...	...	42·5†	...	...
16	...		...	...	...	...	...
18	...	...	...	...	...	43·1	...
20	43·7	...	...	43·4	...	...	...
22	...	...	43·3†	...	...	...	...
24	...	...	...	...	42·7†	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	43·1	...
30	43·8	...	...	43·6	...		...
32	...	...	43·5†	...	...	...	...
34	...	...		...	43·1†	...	...
36	...	...	...	...		...	...
38	...	...	...	...	...	...	...
40	43·9	...	...	...	...	...	...
42	...	...	...	43·7	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	44·0	...	...	...
54	44·0	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	44·1	...	...	...
64	44·0	...	...		...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	44·1	...	...	...	...	...	...
76		...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	DUNOON BASIN.	KYLES OF BUTE.	DUNOON BASIN.	HOLY LOCH.	DUNOON BASIN.		LOCH GOIL.
Date	March 27	March 27	March 27	March 27	March 27	March 27	March 28
Position	Off Knock Hill	Off Bogany	Gantock	Kilmun	Strone Pt.	Coulport	Head
Hour	8.40	11.40	14.0	14.55	15.30	16.15	9.30
Wind	N., 1	N., 1	., 0·5	S., 0·5	S., 1	S.S.W., 2	N.E., 2
Weather & Sea	Snow, smooth	Bright sunshine, smooth	Bright, smooth	Overcast, smooth	Partially overcast, smooth	Overcast, roughish	Overcast, smooth
Depth	44	29	51	13	33	39	11
Temp. of Air	37·5	41·5	38·9	41·9	...	...	38·5
Fathoms							
0	42·1	42·1	42·2	43·6	43·0	43·0	42·9
1	...	...	...	...	...	...	...
2	...	42·4	...	43·0	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	42·2	42·6	...	...	42·8	42·9	42·7
6	...	...	...	...	...	...	...
7	...	...	...	43·0	...	...	...
8	...	42·9	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	...	42·6	...	42·9	42·9	43·9
12	...	...	...	43·0	42·8†	...	
14	42·4†	...	...		...	...	...
16	...	...	...	...	...	...	...
18	...	42·3	...	...	...	42·8	...
20	...	...	42·8	...	...	...	...
22	42·5†	...	...	...	42·5†	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	42·5	...	...	...	42·5	...
30	...		42·7	...	...	...	...
32	42·3†	...	...	...	42·7†	...	...
34	...	...	...	...		...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	42·7	...
40	...	...	42·4	...	...		...
42	42·3†	...	...	...	...	...	...
44		...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	42·6	...	...	...	...
52	...	...		...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH-GOIL.	DUNOON BASIN.	LOCH LONG.		GARELOCH.		
Date	March 28	March 28	March 28	March 28	March 28	March 28	March 28
Position	Off Stuckbeg	Dog Rock	Off Thorn Bank	Arrochar	Row I	Above Narrows	Shandon
Hour	10.30	11.25	12.15	13.20	16.45	17.5	17.30
Wind	E., 4	E., 6	N.E., 6	N.E., strong gale	N.E., 6	N.E., 6	N.E., 5
Weather & Sea	Overcast, smooth	Overcast, rough	Overcast, rough	Snow, smooth	Snow, roughish	Snow, roughish	Sleet, roughish
Depth	46	47	34	11	11	17	21
Temp. of Air	38·8	...	40·2	40·0	35·5	35·7	36·0
Fathoms							
0	43·3	43·0	43·1	43·0	41·9	41·9	41·9
1	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	...	...	43·1	43·0	41·6	...	...
6	...	...	...	...	...	41·8	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	43·6	42·6	42·9	43·0	42·2	...	41·9
12	...	...	42·9†			...	...
14	...	...	...	...	...	...	...
16	...	...	...	...	...	42·1	...
18	...	...	...	...	...		...
20	43·3	42·7	...	...	...	...	42·1
22	...	...	42·6†	...	...	...	
24	43·1†	...	...	...	...	...	...
26	...	42·8	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	42·8†	...	...	...	...
34	43·1†	...		...	...	...	...
36	...	42·5	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	43·1†	...	...	...	...	...	...
46		42·6	...	...	...	...	...
48	...		...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	GARE-LOCH.	KYLES OF BUTE.	LOCH STRIVAN.		ARRAN BASIN.		
Date	March 28	March 29	March 29	March 29	March 30	March 30	March 30
Position	Head	Strone Cotes	Clapochlar Point	Head	Garroch Head	Off Brodick	South of Holy Island
Hour	18.15	14.30	15.25	16.15	11.0	15.40	17.20
Wind	N.E., gale	N.E., 1	N.E., 2	N.E., 2	N., 1	N.N.W., 1	N., 2
Weather & Sea	Snow, smooth	Overcast, rain, smooth	Rain, smooth	Rain, smooth	Overcast, smooth	Dull, rain, roughish	Dull, rain, roughish
Depth	10	20	37	12	65	63	53
Temp. of Air	35·9	40·0	39·8	40·0	44·5	44·4	43·8
Fathoms							
0	41·8	43·0	42·1	42·9	41·9	42·0	41·9
1	...	...	...	42·9	...	...	...
2	...	...	...	...	...	...	...
3	...	...	...	42·8	...	41·9	...
4	41·5	...	...	...	...	...	...
5	...	...	42·7	43·1	41·9	41·9	...
6	...	...	...	43·1	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	42·0	43·1	...	...	...	...	...
10		...	43·0	43·1†	42·1	41·9	41·7
12	...	...	...		...	...	...
14	...	...	...	...	42·0	...	...
16	...	...	43·2	...	...	...	...
18	...	42·9†	...	...	...	...	...
20	...		...	...	...	41·8	41·9
22	...	...	...	...	...	...	...
24	...	...	...	...	42·2	...	...
26	...	...	43·1	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	42·0	...
32	...	...	...	...	...	...	42·0
34	...	...	...	...	42·2	...	...
36	...	...	42·8	...	...	...	...
38	...	...		...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	42·1	42·1
44	...	...	...	...	42·2	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	42·4	42·3
54	...	...	...	...	42·3	...	
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	42·4	...
64	...	...	...	...	42·3		...
66	...	...	...	...		...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	CHANNEL.	ARRAN BASIN.		LOCH FYNE.	ARRAN BASIN.		DUNOON BASIN.
Date	March 31	April 3	April 6	April 7	April 7	April 8	April 9
Position	Mull of Cantyre	Off Drumodune Point, Kilbrennan Sound	Skate Island	Off Strachur	Off Skate Island	South of Holy Island	Gantock
Hour	11.20	12.0	12.40	12.45	17.15	14.0	13.25
Wind	N., 2	N.E., 1–3	N.W., 1	Calm	Calm	0	N.E. by N., 2 or 3
Weather & Sea	Clear, heavy swell	Overcast, roughish	Bright sunshine, smooth	Sunshine and cloud, smooth	Overcast, smooth	Sunshine, smooth	Sunshine and cloud, roughish
Depth	35	43	97	75	...	43	53
Temp. of Air	...	...	46·0	50·0	46·7	45·5	...
Fathoms							
0	43·0	42·0	44·1	44·8	44·0	43·9	44·0
1	...	...	43·9	44·2	44·0	43·1	44·0
2	...	...	...	...	...	...	...
3	...	...	42·8	43·8	43·3	42·8	43·2
4	...	...	...	...	...	...	...
5	42·8	41·8	42·8	43·4	43·1	42·8	42·7
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	43·0	41·9	42·8	43·4	42·5	41·9	42·3
12	...	...	...	...	...	...	...
14	43·0	...	...	...	...	42·0†	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	42·6	43·0	42·6	...	42·3
22	...	41·9	...	...		42·1	...
24	42·8	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	42·4	...	...	...	...
32	...	41·8	...	...	...	42·2	42·3
34	42·9	...	...	43·0	...	...	...
36		...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	42·6	...	...	...	...
42	...	41·9	...	...	...	42·3	42·2
44	...		...	...	...		...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	42·2
54	...	...	...	43·0	...	...	
56	...	...	42·8	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	43·1	...	...	...
76	...	...	42·6		...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	42·7	...	...	...	...
98	...	...		...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	DUNOON BASIN.		ARRAN BASIN.	LOCH STRIVAN.	KYLES OF BUTE.	ARRAN BASIN.	
Date . .	April 10	April 10	April 10	April 14	April 14	April 14	May 16
Position .	Gantock	Off Knock Hill	Garroch Head	Off Clapochlar Point	Off Strone Cotes	Skate Island	Off Skate Island
Hour . .	9.40	12.10	13.50	18.5	14.15	17.50	11.0
Wind . .	0	N.N.W., 1	N., 1	N.N.E., 1	W., 1	S.W., 2	S.W., 4
Weather & Sea	Dull, smooth	Dull, rain, roughish	Rain, dull, smooth	Partially overcast, smooth	Partially overcast, smooth	Overcast, smooth	Thick and rain, rough
Depth .	53	43	64	35	21	107	107
Temp. of Air	...	...	...	...	...	...	47·0
Fathoms							
0	43·8	43·2	43·9	43·0	44·4	43·9	45·1
1	43·7	43·1	...	43·0	...	...	...
2	...	...	...	...	...	...	...
3	42·8	42·7	43·4	42·9	...	...	...
4	...	...	...	...	...	...	...
5	42·5	42·6	43·1	43·0	...	...	45·1
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	42·3	...	...	...	...	...
9	...	...	...	...	...	...	...
10	42·3	42·4	42·5	42·5	42·7	...	44·6
12	...	...	...	...	...	...	...
14	...	...	...	42·5	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	42·3	...	42·2	42·3	42·3	42·7	44·2
22	...	42·3	...	...	...	...	...
24	...	...	...	42·3	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	42·2	...	...	...	43·6
32	42·3	42·3	...	...	...	...	...
34	...	...	...	42·3	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	42·2	43·3
42	42·2	42·3	42·2†	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	43·1
52	42·3	...	42·2†	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	43·0
62	...	...	42·2†	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	42·3	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	42·8
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	42·3	43·0
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	42·9
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	42·4	42·7
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.	DUNOON BASIN.	LOCH FYNE.				
Date . .	May 16	May 17	June 2	June 2	June 4	June 4	June 4
Position .	Garroch Head	Gantock	Off Cuill	Off Dunderave	Off Inveraray	Off Strachur	Off Gortans
Hour . .	14.30	11.30	16.45	17.30	8.15	11.30	13.25
Wind . .	S.E. by E., 1	S.S.W., 3	N.E., 3	N.E., 3	0	N.E., 2	S.W., 0·5
Weather & Sea .	Dull, rain, roughish	Partially clouded, very rough	Rain, roughish	Rain, rough	Cloudy, smooth	Partially overcast, smooth	Dull, smooth
Depth .	63	51	15	33	61	73	26
Temp. of Air	49·0	51·0	48·0	48·1	48·5	51·8	51·2
Fathoms							
0	46·5	45·7	45·8	46·4	45·6	46·5	47·0
1	...	...	...	...	...	...	46·9
2	46·3	...	...	46·3	45·8	...	...
3	...	...	...	...	...	...	46·6
4	46·2	...	...	...	...	...	...
5	...	...	...	46·5	46·1	46·3	46·3
6	...	...	...	...	...	...	...
7	45·7	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	45·5	...	...	...	...
10	45·8	44·4	...	46·3	45·3	...	...
12	...	...	...	46·0	...	...	...
14	44·1	...	45·2	46·0	...	45·4	45·3†
16	...	...		45·3	...	...	...
18	43·8	...	...	...	...	...	...
20	43·7	43·9	...	...	44·5	44·7	...
22	...	...	...	44·3	...	...	...
24	...	...	...	...	...	...	45·0†
26	...	...	...	...	...	...	
28	...	...	...	...	...	...	...
30	43·3	43·9	...	...	44·0	43·9	...
32	...	...	...	43·9	...	...	...
34	...	...	...		...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	43·9	...	...	43·8	43·9	...
42	43·0	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	43·8	...	...	43·3	...	...
52	43·1		...	...	...	43·7	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	43·3	...	...
62	42·9	...	...	...		43·5	...
64		...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	43·3	...
74	...	...	...	...	...		...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.		GARELOCH.				
Date . .	June 4	June 5	June 7	June 7	June 7	June 7	June 7
Position . .	Off Kilfinnan Bay	Off Skate Island	Head	Off Shandon	Close to Shandon Pier	Close to Ardenvohr Shore	Off Barreman Pier
Hour . .	14.45	9.50	11.45	12.15	12.40	13.0	13.15
Wind . .	W.S.W., 0·5	S.E., 4	E., 1	E., 2	E., 2–3	E., 3–4, in gusts	E., 4
Weather & Sea . .	Sunshine, cloudy, smooth	Clear, rough	Cloudy, smooth	Cloudy, smooth	Sunshine and cloud, smooth	Overcast, smooth	Overcast, rough
Depth .	76	106	9	22	6	5	2
Temp. of Air	52·5	49·5	54·0	52·2	...	...	...
Fathoms							
0	48·0	47·3	48·7	47·9	46·7	46·9	48·3
1	47·9	...	...	47·8	...	...	48·3
2	...	...	...	...	...	46·4	
3	47·8	...	47·8	...	46·3	...	...
4	...	...	...	...	...	46·4	...
5	47·7	47·2	...	46·6	46·3		...
6	...	...	...	...		...	...
7	...	...	...	...	...	...	...
8	...	...	46·8	...	...	...	...
9	...	...		...	...	...	...
10	47·3	47·0	...	46·2†	...	...	...
12	...	...	...	...	...	...	...
14	46·6†	...	...	46·1†	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	45·7	...	45·9†	...	...	...
22	...	...	...		...	...	...
24	45·7†	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	43·8	...	...	...	...	...
32	...	...	...	...	...	...	...
34	44·0†	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	43·5†	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	43·4	...	...	...	...	...
52	...	...	...	...	...	...	...
54	43·2†	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	43·1†	43·0†	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	43·1†	...	...	...	...	...	...
76		...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	43·0†	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	43·0†	...	...	...	...	...
106	...		...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	GARELOCH.						
Date . .	June 7	June 7	June 7	June 7	June 7	June 7	June 7
Position .	North of Barreman Pier	Between Clynder Pier and opposite Shore	Opposite Clynder, to Weather Shore	100 Yards nearer Shore	Close to Ardenvohr Shore	20 Yards from Shore	Above Narrows
Hour . .	13.30	14.0	14.20	...	...	...	15.10
Wind . .	E., 4	E., 4	E., 4	...	...	...	E., 3
Weather & Sea . .	Overcast, showers, rough	Overcast, rain, roughish	Overcast, smooth	...	...	...	Overcast, smooth
Depth .	13	16	12	...	...	...	21
Temp. of Air	52·1	...	...	...	...	...	...
Fathoms							
0	48·0	47·3	47·5	47·4	47·0	47·0	47·6
1	48·0	47·3	47·4	47·3	46·8	46·9	...
2	47·5	47·3	47·3	47·1	46·9	46·9	47·5
3	47·3	47·2	46·9		46·9		...
4	47·2	47·0	46·7	...	46·5	...	...
5	46·6	46·3	46·3	...	46·6	...	46·3
6	...	...	46·3	...		...	...
7	...	...	...	...	...	...	...
8	46·2	46·1	46·1	...	...	...	...
9	...	...	...	...	...	...	...
10	46·0	45·9	46·1†	...	...	...	46·0
12	46·1	...		...	...	...	...
14		45·9†	...	...	...	...	45·9†
16	...		...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	...	...	...	...	45·8
22	...	...	...	...	...	...	
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	GARELOCH.		LOCH STRIVAN.				
Date	June 7	June 7	June 9	June 9	June 9	June 9	June 9
Position	Off Shandon Pier	Sea Shore, directly opposite Shandon	Off Strone Point	½ mile N.E. of Strone Point	Toward Pt. Shore, opposite last	Off Artaraig Hills	¾ mile from White House
Hour	15.40	16.10	13.20	13.45	14.10	15.20	15.35
Wind	E., 3 or 2	E., 3 or 2	W., 2	W., 0.5 in lee of land	W., 2	N.E., 3, gusts 4	N.W., 3
Weather & Sea	Overcast, rain, smooth	Overcast, roughish	Cloud and sunshine, smooth to roughish	Smooth	Cloud and sunshine, smooth to roughish	Cloudy, roughish	Overcast, smooth to roughish
Depth	4	5	36	6	5	23	18
Temp. of Air	...	...	58·0	61·7	56·4	...	...
Fathoms							
0	47·8	48·3	49·0	47·3	51·3	49·5	51·6
1	47·3	...	48·5	47·0	49·0	47·2	47·2
2	...	47·8	47·0	46·8	47·3	47·0	46·8
3	46·4	...	47·1	46·7	47·0	...	46·4
4		47·4	...	46·8	46·9	...	...
5	...		46·1	46·3	45·9	46·1	...
6	...	...	...			...	...
7	...	...	...	...	...	...	45·0
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	...	45·0	...	...	...	...
12	...	...	...	...	...	44·0	43·9
14	...	...	44·1†	...	...		...
16	...	...	...	...	...	...	43·6†
18	...	...	...	...	...	...	
20	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	44·1†	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	44·1†	...	...	...	...
36	...	...		...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH STRIVAN.						ARRAN BASIN.
Date	June 9	June 9	June 9	June 9	June 9	June 9	June 11
Position	¼ mile from White House, Weather Shore	Same, 30 yards removed	Opposite Shore from last	Off Point above Berry's Pier	Off Clapochlar Point	½ mile N.E. of Strone Point	Bet. Allans and Little Cumbrae
Hour	16.0	16.10	16.20	16.40	16.50	17.25	8.50
Wind	N.W., 3	...	Blowing in a slanting direction along and across the Loch	...	N.W., 3-4	W., 2	S., 0·5
Weather & Sea	...	...	...	...	Overcast, roughish	Overcast, smooth	Bright, smooth
Depth	...	...	...	...	...	...	...
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	50·9	48·0	47·8	48·0	48·0	47·4	47·0
1	47·4	47·0	47·1	47·8	48·2	47·2	46·3
2	47·0	47·0	46·9	47·1	47·9	46·9	46·1
3							
4	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...
14	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48			...	...	...	...	...
50			...	...	...	...	...
52			...	...	...	...	...
54	At these	two points	...	...	...	...	...
56	are recorde	d tempera-	...	...	...	...	...
58	tures in eit	her side of	...	...	...	...	...
60	a tide rip.	A body of	...	...	...	...	...
62	warm green	water was	...	...	...	...	...
64	being carrie	d along this	...	...	...	...	...
66	Shore.		...	...	...	...	...
68			...	...	...	...	...
70			...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

1888.	ARRAN BASIN.		LOCH LONG.	LOCH FYNE.	DUNOON BASIN.	LOCH GOIL.	ARRAN BASIN.
Date . .	June 11	June 11	June 11	July 18	Aug. 14	Aug. 15	Aug. 19
Position .	Between Cumbrae and Fairlie	Fairlie Anchorage	Head	Off Strachur	Strone Point	Stuckbeg	Off Brodick
Hour . .	9.10	9.30	9.0	10.15	15.40	14.45	13.20
Wind . .	S., 1–2	S., 2, freshening	N.E., 1–3, squally	N.E., 0·5	Light	0	S., 1
Weather & Sea . .	Bright, smooth	Bright, cloudy, smooth	Bright, cloudy, smooth	Dull, smooth	Fine	Fine and sunny	Hazy, sunshine, smooth to ripple
Depth .	...	...	11	73	...	...	63
Temp. of Air	...	...	...	57·0	...	66	59·0
Fathoms							
0	47·0	47·8	46·5	49·5	52·3	54·6	...
1	...	...	...	49·3	51·8	...	...
2	46·7	47·3	...	...	...	...	...
3	...	...	...	47·4	51·8	...	...
4	...	...	...	...	...	...	...
5	46·4	46·8	46·3	47·2	51·7	50·0	...
6			...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	...	...	45·1	47·0	49·6	...	...
12	...	...		...	...	...	...
14	...	...	...	47·0†	...	47·1†	...
16	...	...	...	...	49·0	...	...
18	...	...	...	...	...	...	...
20	...	...	...	46·9	...	...	...
22	...	...	...	...	...	...	...
24	...	...	...	46·8†	...	44·6	...
26	...	...	...	...	47·6	...	...
28	...	...	...	...	...	...	...
30	...	...	...	45·4	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	44·9†	...	43·8	...
36	...	...	...	...	45·5	...	...
38	...	...	...	...		...	...
40	...	...	...	44·4	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	44·1†	...	43·5	...
46	...	...	...	...	...		...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	43·9	...	...	47·7
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	43·6	...	...	47·2
64	...	...	...	...	...	...	
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	43·7	...	...	...
74	...	...	...		...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.	GARELOCH.		LOCH FYNE.			
Date	Aug. 19	Aug. 20	Aug. 20	Aug. 24	Aug. 24	Aug. 25	Aug. 25
Position	Off Brodick	Head	Off Shandon	Cuill	Off Dunderave	Off Inveraray	Off Strachur
Hour	...	15.30	15.50	15.30	16.15	10.0	11.10
Wind	...	0	0	S.W., 0.5	S., 1	S., 2–3	S., 3–4
Weather & Sea	...	Wet	Wet	Light cloud, smooth	Dull, smooth	Bright, smooth	Bright, smooth
Depth	65	9	21	16	35	63	75
Temp. of Air	...	57·0	56·2	64·0	...	62·7	...
Fathoms							
0	55·1	57·9	56·0	60·8	57·1	59·6	56·5
1	...	...	...	55·2	55·4	...	55·2
2	...	...	...	54·1	54·2	...	53·6
3	...	57·0	...	...	...	...	...
4	...	...	...	...	...	53·3	...
5	...	...	...	53·4	52·9	...	52·4
6	...	...	...	53·3	...	...	...
7	...	...	...	52·5	...	52·2	...
8	...	51·9	...	...	...	...	...
9	...		...	...	...	...	...
10	53·7	...	52·0	51·6	52·0	50·9	51·8
12	...	...	...	51·2	51·8	...	...
14	...	...	...	49·4†	50·3	49·8†	...
16	...	...	...		49·5†	...	...
18	...	...	...	...	...	...	...
20	52·4	...	51·2	...	48·3	48·1	48·3
22	...	...		...	48·1	47·6	...
24	...	...	...	...	45·5	47·0†	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	45·1	46·0	46·5
32	...	...	...	...	...	...	...
34	...	...	...	...	44·3	45·8†	...
36	...	...	...	...		...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	45·1
42	...	...	...	...	...	45·0	...
44	48·2	...	...	...	...	45·0†	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	44·3
52	...	...	...	...	...	44·3	...
54	57·6	...	...	...	...	44·4†	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	44·0	...
64	47·1	...	...	...	...		43·7
66		...	...	...	...	...	...
68	...	...	...	...	...	...	43·5†
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	43·8
76	...	...	...	...	...	...	
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH FYNE.						
Date	Aug. 25	Aug. 25	Aug. 25	Aug. 27	Aug. 27	Aug. 27	Sept. 1
Position	Off Furnace	Off Cuill	Off Dunderave	Off Cuill	Off Dunderave	Off Inveraray	Off Inveraray
Hour	12.25	16.50†	17.20	16.0	16.40	17.25	18.30
Wind	S., 1	S., 2–3	S., 0–1	S., 4–5	S.W., 3–4	S., 2	S.W., 1
Weather & Sea	Bright, smooth	Bright, smooth	smooth	Dull, squally, ruffled	Driving showers, ruffled	Bright	Rain, smooth
Depth	36	16	36	16	36	63	63
Temp. of Air	61·5	63·0	...	...	57·0	...	...
Fathoms							
0	56·4	62·3	60·8	56·8	58·3	58·0	55·8
1	56·2	...	...	58·2	...	57·2	...
2	53·9	...	57·3	58·4	58·2	...	...
3	...	53·7	...	58·4	...	55·3	...
4	52·4	...	52·1	58·1	...	...	...
5	52·4	51·9	52·0	55·1	55·7	54·5	...
6	...	...	...	...	...	...	...
7	...	...	...	...	50·2	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	51·9	50·2	50·3	51·4	52·0	52·1	52·5
12	51·9	48·6†	...	...	48·5	...	...
14	50·3†	47·4†	49·2†	48·7†	50·6†	51·0†	...
16	...		...		...	...	...
18	...	...	...	...	...	...	...
20	49·3	...	47·5	...	48·5	48·9	49·3
22	...	...	...	...	45·8	...	...
24	48·1†	...	46·7†	...	46·4†	47·1†	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	47·1	...	46·0	...	46·1	45·9	...
32	...	...	...	...	...	...	...
34	46·0†	...	45·8†	...	45·2†	...	...
36		...		...		...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	45·0	45·0
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	44·3	48·2
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	44·1	45·2
64	...	...	...	...	...		
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	ARRAN BASIN.	LOCH LONG.		DUNOON BASIN.	LOCH GOIL.		DUNOON BASIN.
Date	Aug. 29	Sept. 3	Sept. 3	Sept. 3	Sept. 3	Sept. 3	Sept. 3
Position	Garroch Head	Arrochar	Thornbank	Dog Rock	Stuckbeg	Head	Coulport
Hour	12.0	13.15	14.10	15.15	16.10	16.50	18.15
Wind	W.N.W., 1–2	S.W., 1	S.W., 1	W., 0·5	W., 0·5	W., 0·5	W., 0·5
Weather & Sea	Overcast, showers, roughish	Dull, rain, smooth	Dull, smooth	Dull, smooth	Dull, smooth	Dull, smooth	Dull, smooth
Depth	63	11	33	50	44	13	33
Temp. of Air	57·0	...	...	...	...	...	...
Fathoms							
0	55·0	55·7	56·0	56·1	56·0	55·3	55·6
1	...	55·7	...	...	55·7	...	...
2	54·9	...	54·3	...	...	55·1	55·4
3	...	54·5	...	54·8	54·5	...	...
4	...	...	52·6	...	...	54·8	...
5	54·5	53·2	...	54·0	52·9	...	54·0
6	...	...	...	...	...	...	...
7	...	52·4	...	...	...	51·4	...
8	...	...	51·2	...	...	...	...
9	45·8	...	...	...	...	51·1	...
10	...	52·2	...	51·0	50·5	...	...
11	...		...	...	...	...	...
12	...	...	50·3	...	...	50·1	50·9
13	...	...	...	...	...		...
14	...	...	...	...	...	...	...
15	...	...	...	50·6	47·2	...	...
16	...	...	51·1	...	...	...	...
17	...	...	...	...	...	...	...
18	...	...	...	...	45·4	...	...
19	...	...	...	...	...	...	...
20	51·9	...	...	50·6	...	...	...
22	...	...	49·1	...	44·5†	...	50·2
24	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...
28	...	...	48·0	49·5†	...	...	...
30	50·2	...	...	...	...	...	...
32	...	...	46·4	...	43·8†	...	49·2
34	...	...		...	...	...	
36	...	...	...	...	...	...	...
38	...	...	...	48·2†	...	...	...
40	...	...	...	...	...	...	...
42	49·2	...	...	...	44·0†	...	...
44	...	...	...	...		...	...
46	...	...	...	...	...	...	...
48	...	...	...	48·1†	...	...	...
50	...	...	...		...	...	...
52	48·8	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	50·0	...	...	...	...	...	...
64		...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	..	...	...
74	...	...	...	...	...	..	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	GARELOCH.				DUNOON BASIN.	HOLY LOCH.	DUNOON BASIN.
Date	Sept. 6	Sept. 6	Sept. 6	Sept. 6	Sept. 8	Sept. 8	Sept. 8
Position	Head	Off Shandon	Row	Row	Gantock	Off Kilmun	Strone Point
Hour	14.15	14.40	15.15	15.30	12.0	13.10	13.50
Wind	S.W., 4–6, squalls	W.S.W., 4	W.S.W., 5	W.S.W., 4	S.W., 0·5, freshening	S.W., 0·5	S.W., 0·5
Weather & Sea	Dull, rain, ripple	Dull, rain, smooth	Dull, rain, smooth	Dull, rain, smooth	Bright, smooth	Bright, smooth	Bright, smooth
Depth	10	23	21	13	51	14	33
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	55·0	54·8	55·0	54·5	55·9	55·0	55·8
1	...	...	...	54·4	...	54·9	...
2	...	54·8	...	54·0	54·0	...	...
3	...	...	...	...	...	54·7	...
4	54·9	54·5	...	...	53·3	...	53·0
5	...	...	...	54·2	...	53·9	...
6	...	...	...	...	53·0	...	...
7	...	...	...	53·8	...	...	...
8	...	54·0	...	...	...	52·9	52·0
9	54·1	...	...	...	...	...	...
10	...	...	54·0	...	52·4	...	...
11	...	...	...	...	...	...	...
12	...	53·1	...	52·5	...	...	51·7
13	...	...	...	...	...	52·0	...
14	...	...	...	...	...	...	...
15	...	...	...	...	52·2	...	...
16	...	...	...	...	...	...	...
17	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...
20	...	...	53·2	...	51·6	...	...
22	...	52·5	...	...	...	...	51·1
24	...	...	...	...	51·7†	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	51·5	...	...
32	...	...	...	...	...	...	50·0
34	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	51·8	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	52·0†	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	52·0	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	KYLES OF BUTE.					LOCH STRIVEN.	
Date	Sept. 8	Sept. 20	Sept. 20	Sept. 20	Sept. 20	Sept. 20	Sept. 20
Position	Bogany	Ardlamont Point	Ormidale, Loch Ridun	Angle	Off Strone Cotes	Off Strone Point	Off Clapochlar Point
Hour	15.30	9.55	11.35	12.5	13.5	13.30	14.15
Wind	Calm	N.E., 1	N.E., 1	N.E., 1	N.E., 1	N.E., 1	N.E., 1
Weather & Sea	Bright, smooth	Dull, hazy, smooth	Bright, hazy, smooth	Bright, hazy, smooth	Bright, hazy, smooth	Bright, hazy, smooth	Bright, hazy, smooth
Depth	27	24	12	29	19	36	36
Temp. of Air	...	...	...	...	...	...	...
Fathoms							
0	55·9	54·7	54·5	54·5	54·2	55·0	55·9
1	...	...	54·3	...	...	...	...
2	...	...	...	...	...	...	...
3	54·4	54·6	...	...	...	...	...
4	...	...	54·0	...	...	...	...
5	...	...	...	53·9	...	54·0	54·5
6	53·1	...	53·2	...	...	...	...
7	...	...	...	...	...	...	...
8	...	53·9	52·5	53·1	52·7	...	...
9	...	...	...	...	...	...	...
10	...	...	...	...	...	52·5	52·7
11	52·2	...	52·2	...	...	...	...
12	...	...		...	...	...	...
13	...	53·3	...	...	...	...	...
14	...	...	...	...	...	...	...
15	...	...	...	52·4	...	51·4	51·8
16	50·2	...	...	...	...	...	...
17	...	...	...	...	...	...	...
18	...	52·2	...	52·1	51·0	...	...
19	...	...	...	...		...	...
20	...	...	...	...		...	...
22	...	51·4†	...	...	...	...	...
24	...		...	...	...	49·5†	49·5†
26	51·1	...	...	...	...	...	...
28		...	...	52·2	...	...	...
30	...	...	...		...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	48·7†	48·4†
36	...	...	...	...	...		
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH STRIVAN.	LOCH LONG.	DUNOON BASIN.		SOUND OF JURA.	LOCH ABER.	
Date	Sept. 20	Sept. 21	Sept. 22	Sept. 24	Oct. 1	Oct. 6	Oct. 8
Position	Head	Knap Point	Cloch, W. ½ S. 1 mile	Blairmore	Off Crinan, inside Doris Mor	2 miles above Corran Light	2 miles above Corran Light
Hour	15.5	12.20	16.15	14.35	17.0	16.0	12.25
Wind	N.E., 1	Calm	S.W., 2	E., 1–2	N.N.E., 3–4	N.E. by N. 3–4	W., 1
Weather & Sea	Bright, hazy, smooth	Sunshine, smooth	Sunshine, roughish	Sunshine, smooth	Sunshine, rough	Overcast, smooth	Bright, cloudy, smooth
Depth	11	26	25	33	73	80	81
Temp. of Air	...	...	...	...	45·3	...	...
Fathoms							
0	55·9	55·0	54·0	53·8	53·5	51·5	52·5
1	55·8	...	...	...	...	51·8	52·6
2	55·7	...	...	53·1	...	52·2	52·5
3	55·6	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	52·4	51·6	51·8	52·7	...	52·3	53·0
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	51·4	...	51·9	...	53·5	52·5	52·8
11		...	...	...	...	...	...
12	...	...	...	51·0	...	...	...
13	...	...	...	...	...	...	...
14	...	...	...	...	...	...	...
15	...	49·9	...	...	...	...	...
16	...	...	51·7	...	...	...	...
17	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...
20	...	...	51·5†	...	53·7	53·1	53·1
22	...	...	...	51·2	...	...	...
24	...	50·6†	51·7	...	...	...	...
26	...			...	...	...	...
28	...	...	...	...	...	...	...
30	...	...	...	...	...	52·9	...
32	...	...	...	51·6	53·5	...	...
34	...	...	...		...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	52·9	52·9
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	53·1	...
52	...	...	...	...	53·5	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	52·9†	...
60	...	...	...	...	...	...	52·9
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	52·9†	...
70	...	...	...	...	...	...	...
72	...	...	...	...	53·7	...	...
74	...	...	...	...		...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	53·1†	...
80	...	...	...	...	...		53·1
82	...	...	...	...	...		
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	FIRTH OF LORNE.	LOCH ETIVE.	LOCH FYNE.				
Date	Oct. 9	Oct. 11	Oct. 16	Oct. 16	Oct. 16	Oct. 16	Oct. 16
Position	Off Loch Spelvie	Off Ru Aird Point	Otter Beacon	Between Gair Loch and Gortans Point	Off Paddy Rocks	Off Furnace	Off Strachur
Hour	16.30	16.35	12.20	13.25	14.15	15.0	15.45
Wind	S.W., 1	W.S.W., 2	S.W., 1	S.W., 1–2	S.W., 1	S.W., 1–2	Calm
Weather & Sea	Cloudy, fine, showers	Rain, smooth	Overcast, smooth	Overcast, smooth	Overcast, smooth	Overcast, smooth,	Overcast, smooth
Depth	40	68	21	36	14	35	72
Temp. of Air	52·9	...	...	51·6	...	51·3	...
Fathoms							
0	53·0	52·8	49·8	49·9	...	49·9	50·0
1	53·0	...	49·8	...	...	...	...
2	...	...	...	...	...	...	49·9
3	53·1	...	...	...	49·8	...	...
4	...	...	...	...	...	...	...
5	53·1	52·2	49·7	49·7	...	49·6	49·7
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	49·8	...	49·7
9	...	...	...	...	...	...	...
10	53·2	51·7	49·8	50·0	...	49·9	...
11	...	...	...	...	50·0†	...	...
12	...	51·3†	50·1†	49·9†		49·8	50·1
13	...	...	...	...	...	...	50·1†
14	...	...	...	...	...	...	...
15	53·5	...	50·1	...	...	...	49·7
16	...	...		...	...	...	...
17	...	50·7†	...	49·9†	...	49·2	...
18	...	...	...	...	...	...	...
19	53·3†	...	...	...	...	...	...
20	...	...	...	...	...	...	48·2
22	...	...	...	...	...	...	...
24	...	50·0†	...	50·0†	...	48·4	...
26	...	...	...		...		...
28	53·3†	...	...	...	...	...	...
30	...	...	...	...	...	...	46·2
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...
36	...	48·8†	...	...	...	...	...
38	53·4†	...	...	...	...	...	...
40		...	...	...	...	...	45·0†
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	48·7†	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	44·1†
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	49·1†	...	...	...	...	...
58	...		...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	44·2†
64	...	...	...	...	...	...	
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH FYNE.				ARRAN BASIN.		LOCH STRIVEN.
Date	Oct. 17	Oct. 17	Oct. 17	Oct. 18	Oct. 19	Oct. 19	Oct. 20
Position	Off Cuill	Off Dunderaine	Off Inveraray	Off Strachur	Off Kilfinnan Bay	Off Skate Island	...
Hour	12.0	12.45	13.10	12.30	14.35	16.5	14.15
Wind	Calm	Calm	Calm	S. by E., 3	S., 2–3	S.S.E., 3	E., 2–3
Weather & Sea	Overcast, smooth	Dull, smooth	Overcast,	Overcast, misty, roughish	Overcast, misty, roughish	Mist and sunshine, roughish	Sunshine, haze, roughish
Depth	16	35	64	78	76	105	36
Temp. of Air	48·3	49·3	49·2	51·2	53·0	53·0	...
Fathoms							
0	49·9	50·0	49·5	49·8	49·9	50·8	50·5
1	...	...	...	...	...	50·5	...
2	49·9	...	...	49·8	...	...	...
3	...	...	49·9	...	...	50·8	...
4	...	...	...	...	...	...	...
5	49·8	49·9	49·8	49·6	49·7	50·8	50·2
6	...	...	...	...	...	...	...
7	...	...	49·9	...	...	...	...
8	...	...	...	49·8	...	...	...
9	...	...	...	...	49·9	...	...
10	49·2	49·6	50·0	...	...	50·5	50·3
11	49·0†	...	49·9	50·0	...	...	...
12	48·8†	49·1	49·6†	49·9†	...	50·5†	50·2†
13		...	...	...	...	...	...
14	...	...	...	...	...	...	...
15	...	...	...	49·8	50·0	50·5	...
16	...	...	...	...	...	...	...
17	...	48·5	48·7†	49·7†	...	...	50·1†
18	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...
20	...	...	...	49·0	50·0	50·2	...
22	...	...	...	...	...	...	...
24	...	47·5	47·5†	47·3†	...	...	50·0†
26	...		...	...	...	...	
28	...	...	...	...	...	...	...
30	...	...	...	47·4	50·2	50·3	...
32	...	...	46·0†	...	...	...	...
34	...	...	...	46·2†	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...
40	...	...	...	...	...	50·0	...
42	...	...	44·2†	45·0	...	...	...
44	...	...	...	...	50·0†	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	49·7	...
52	...	...	44·2†	44·2	...	...	...
54	...	...		...	49·7†	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	49·4	...
62	...	...	...	44·1	...	...	...
64	...	...	...		49·7†	...	...
66	...	...	...	...		...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	48·8†	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	48·5†	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	48·6	...
96	...	...	...	...	...		...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	LOCH STRIVEN.			GARE-LOCH.	ESTUARY.	LOCH LONG.	LOCH GOIL.
Date	Oct. 20	Oct. 20	Oct. 20	Oct. 22	Oct. 22	Oct. 23	Oct. 23
Position	Off Berry's Pier	Off Artaraig Hills	Head	Off Shandon	Off Rose-neath	Between Knap Point and Thorn-bank	Off Stuckbeg
Hour	15.0	15.40	16.5	11.20	12.35	13.40	15.10
Wind	E. by S., 3	S.E., 3	E., 2	E., 1	Calm	W.S.W., 1	W., 1–2
Weather & Sea	Haze, sunshine, roughish	Haze, sunshine, roughish	Sunshine, overcast, smooth	Sunshine, haze, smooth	Sunshine, haze, smooth	Sunshine, cloudy, smooth	Sunshine, cloudy, smooth
Depth	37	23	12	23	13	33	46
Temp. of Air	58·2	...	57·2	47·5	...	...	...
Fathoms							
0	50·5	50·2	...	49·8	...	49·8	49·9
1	...	...	50·2	...	...	...	...
2	...	50·2	...	49·8	...	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	50·2	50·2	...	49·7	...	49·8	49·5
6	...	...	50·1	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	50·8	...	...
9	...	...	...	...	...	...	...
10	50·3	50·2	50·2†	...	50·5	50·2	49·7
11	...	50·1		50·0	50·8	50·1	...
12	...	...	...	50·2†		...	...
13	50·1	...	...	...	...	...	...
14	...	...	...	...	...	...	...
15	...	...	...	...	...	...	...
16	...	50·2	...	50·2	...	50·7	...
17	...		...		...	...	46·2†
18	50·0	...	...	...	...	...	...
19	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...
22	...	...	...	...	...	51·1	...
24	...	...	...	...	...		45·2†
26	49·8	...	...	...	...	...	...
28		...	...	...	...	...	...
30	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...
34	...	...	...	...	...	...	45·0†
36	...	...	...	...	...	...	
38	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

1888.	DUNOON BASIN.	GARE-LOCH.	DUNOON BASIN.	ARRAN BASIN.	LOCH FYNE.	LOCH LONG.	LOCH GOIL.
Date . .	Oct. 24	Oct. 25	Oct. 25	Oct. 29.	1887 Oct. 13	1887 Oct. 15	1887 Oct. 15
Position .	Off Blair-more	Off Shandon	Off Knock Hill	Garroch Head	Off Inveraray	Dog Rock	Off Stuckbeg
Hour . .	16.15	11.10	15.10	8.20	12.30	12.20	13.15
Wind . .	Calm	S.W. by S., 4–5	S.W. by S., 4	W.S.W., 4	N.W., 3	N., 1	N., 2
Weather & Sea . .	Overcast, rain, swell	Rain, rough	Overcast, rain, rough	Sunshine, cloudy, very rough	Sunshine, ripple	Ripple	Sunshine, ripple
Depth .	32	22	41	56	59	53	44
Temp. of Air	...	...	...	...	48·8	...	47·2
Fathoms							
0	50·2	50·0	50·3	51·0	51·3	52·6	51·5
1	...	50·0	...	...	...	...	...
2	50·2	...	...	...	51·2	...	...
3	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...
5	50·5	49·9	50·2	...	51·2	...	51·4
6	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...
10	50·8†	49·9†	50·5	50·9	51·2	52·5	51·6
11	...	...	...	...	...	...	...
12	...	50·2†	...	...	...	...	...
13	...	...	...	...	...	...	...
14	...	...	...	...	...	...	...
15	50·7†	50·1†	50·5	51·1	51·1	53·0	...
16	...	...	...	...	...	...	50·1†
17	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...
20	51·0†	...	50·5	...	51·1	...	...
22	...	...	...	...	...	52·3	48·3†
24	...	...	...	51·0†	...	...	...
26	...	...	...	...	...	...	...
28	...	...	...	...	48·2	...	...
30	...	...	50·8	...	...	...	...
32	...	...	...	...	...	52·7	48·1†
34	...	...	...	50·9†	...	...	...
36	...	...	...	...	...	...	...
38	...	...	...	...	46·6	...	...
40	...	...	...	...	...	...	...
42	...	...	...	...	...	52·9	...
44	...	...	...	51·1†	...	...	...
46	...	...	...	...	...	...	...
48	...	...	...	...	46·0	...	...
50	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...
56	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...

† Observation made 1 fathom deeper than indicated.

On Silica and the Siliceous Remains of Organisms in Modern Seas. By **John Murray**, LL.D., Ph.D., &c., and **Robert Irvine**, F.C.S.

(Read March 16, 1891.)

In a former paper to this Society, we pointed out the important role played by carbonic acid in modern seas, with special reference to the vast deposits of carbonate of lime now taking place in coral reefs and those other calcareous deposits known as Globigerina and Pteropod Oozes. It was pointed out that carbonic acid was the chief agent in the disintegration of felspars and other silicates of the earth's surface, that it was concerned in all the changes that result in the secretion of carbonate of lime by marine organisms from any of the lime salts in sea-water, that a vast amount of carbonic acid was being locked up in the calcareous deposits now in process of formation on the sea-bed, and that there was an accumulation of these calcareous deposits chiefly towards the equatorial regions of the ocean basins. In the present paper we propose to deal with the great antagonistic power to carbonic acid, viz., silica, and with the siliceous organic remains in the ocean.

Silica, or silicic acid, is an oxide of silicon, indeed the only oxide of that element known to exist, and resembles in many of its properties the oxide of carbon (carbonic acid); it is probably the widely distributed body in the surface and subsurface layers of the earth's crust. When the earth's surface was at a high temperature, probably all the silica was in combination with lime, magnesia, iron, alumina, and alkalies—forming the great series of silicates. At a high temperature silica has a great affinity for bases, but at a low temperature it is in most cases replaced by carbonic acid from its compounds. It thus happens that from early geological times carbonic acid has been extracted from the atmosphere, and locked up in the solid crust of the earth. If this process goes on without limitation life will ultimately become impossible on the earth's surface. From volcanoes and fissures carbonic acid is given off, owing, apparently, to the silica again taking the place of the carbonic acid in the heated rocks below. In all the ordinary disintegrating pro-

cesses at work at the earth's surface, the carbonic acid replaces the silica from its bases, the silica being thus set free to form quartz, or a hydrated variety of silica like opal, for example.

Although there are enormous numbers of organisms in the ocean that secrete silica to form their frustules, shells, or skeletons, the remains of these siliceous organisms do not play nearly so large a part in the formation of the deposits of modern seas as the remains of carbonate of lime organisms dealt with in our former paper. For our present purpose the siliceous organisms of modern seas may be divided into the Sponges, which live on the bottom, or belong to the Benthos,* and the Diatoms and Radiolarians, which have a pelagic habitat, or belong to the Plankton.* The siliceous sponges belonging to the Tetractinellida, Monaxonida, and Hexactinellida, are universally distributed over the floor of the ocean, the Hexactinellida being limited to the deep sea, *i.e.*, to depths greater than 100 fathoms. Although universally distributed over the ocean's floor, the spicules of sponges rarely make up over 1 or 2 per cent. of a deep-sea deposit, except in those limited areas where there are extensive patches of these sponges growing on the bottom, when the spicules in some samples of a deposit may rise as high as 20 per cent. At Kerguelen, in 120 fathoms, over one hundred specimens of *Rossella antarctica* were obtained in one haul of the trawl; at Zebu, Philippines, a large number of *Euplectella* and other sponges were obtained in 100 fathoms; off the Ki Islands, in 129 fathoms, there were eighteen species of Hexactinellida and a large number of individuals; in the Atlantic, near the Cape Verdes, there was procured in 1525 fathoms a large specimen of *Poliopogon amadou* ($2 \times 1\frac{1}{2}$ feet) attached to the branches of an Alcyonarian coral (*Pleurocorallium johnsoni*); off the Kermadecs, in 630 fathoms, there was another *Poliopogon* (*Poliopogon gigas*), measuring $2 \times 3\frac{1}{2}$ feet, and this was but a fragment of what was apparently an enormous sponge. In the Faroe Channel large numbers of specimens of *Pheronema* (*Holtenia*) were dredged from a depth of 530 fathoms, while trawlings near the same spot did

* Benthos (βένθος, bottom of the sea) is a term introduced by Haeckel for all those organisms living on or creeping over the bottom of the sea, in contradistinction to Plankton, which, as extended by him, includes all those organisms swimming about in the sea or carried along in ocean currents (*Plankton-Studien*, Jena, 1890).

not yield any specimens. Many other examples might be given to show that the sponges are clustered in patches over the bed of the ocean, with intervening more or less barren spaces. On the whole, siliceous sponges are most abundant in moderate depths on the Blue Muds along continental shores and in pelagic deposits, and are more numerous on Diatom and Radiolarian Oozes than on Globigerina and Pteropod Oozes. The spicules of sponges frequently show signs of undergoing solution, in the widening of the axial canals, and the disappearance or thinning of the more delicate processes. The spicules contain from 6 to 7 per cent. of water, or in some cases as much as 13 per cent.,* associated with organic matter,† and belong to the variety of silica known as opal.

When we turn to the Diatoms and Radiolarians, we find that they are universally distributed throughout the surface and subsurface waters, indeed, the tow-net experiments carried out on board the "Challenger" appear to prove that some species of Radiolarians live throughout all the intermediate depths of the ocean.

Diatoms are abundant in all estuaries and wherever there is a low salinity from the admixture of river water, but they are found, although more sparingly, in the very saltest waters of the ocean. In the waters of the great Southern Ocean and Antarctic regions they occur in enormous quantities on the surface, filling the tow-nets with a slimy, yellow-brown mass. This slimy mass of siliceous algæ consisted chiefly of *Rhizosolenia*, *Chætoceros*, and *Thalassiothrix*, and when dried over a stove presented a felted appearance like some specimens of asbestos. On analysis this dried mass yielded :—

Silica soluble in acid, ...	1·00	per cent.
Silica insoluble in acid, . . .	76·00	,,
Alumina, ...	1·38	,,
Organic matter, ...	16·75	,,
Water, ...	4·87	,,
	100·00	,,

In the Arctic Ocean, and in the seas around the Shetland Islands, Diatoms are also at times found in vast floating banks, and they

* Thoulet, *Comptes Rendus*, tome xcviii. p. 1000, 1884.
† Sollas, *Zool. Chall. Exp.*, part lxiii. pp. 47 *et seq.*

can be collected in tow-nets as a yellowish slimy mass. Herring-fishers are sometimes hampered in their operations by the vast floating banks of these Algæ.* In the Arafura Sea and other tropical and subtropical regions the "Challenger" Expedition also collected great numbers of Diatoms at the surface, especially where there was brackish water, or, at least, water of a relatively low salinity. In the true oceanic waters of the tropical regions the number of species of Diatoms is probably as numerous as in polar waters, but the individuals are not nearly so abundant. In a Diatom ooze from lat. 54° S., 48 species of Diatoms were observed in the deposit, while in a tropical Radiolarian ooze, lat. 6° N., 51 species were recognised; of these 14 species are common to the two stations. In the former case the Diatom remains make up over 50 per cent. of the whole deposit, in the latter not more than 2 or 3 per cent. Some large species of tropical *Etmodiscus* (*Coscinodiscus*) have an extremely thin shell of silica, and indeed, all the Diatom frustules of species that live in truly pelagic waters of the tropical and sub-tropical regions are exceedingly thin and delicate compared with those in colder and coast waters. When Diatoms cannot be observed directly in the tow-net gatherings, they can almost always be found in the stomachs of *Salpæ*, *Doliolum*, and other marine animals. The specimens of Diatoms met with in the open sea all belong to pelagic species, but it is not uncommon to meet with attached forms fixed to the backs of Copepods and other Crustacea, as well as on pelagic Molluscs. These siliceous pelagic Algæ or Diatoms, together with other Algæ, some of which secrete carbonate of lime—Coccospheres and Rhabdospheres—appear to live only in those upper layers of oceanic waters that are affected by sunlight, and they are the original source of the food of the vast majority of animals living at the surface and on the bottom of the sea, for on falling to the bottom the Diatoms still retain a portion of their organic matter, and thus supply with nourishment those animals, like Echinoderms and Annelids, which live at the bottom by eating the mud or ooze there in process of accumulation.

The Radiolarians, unlike the Diatoms, are rarely met with in any numbers in estuaries or near the mouths of rivers, their true habitat being in the open ocean; they belong to oceanic as distinguished

* Pearcey, *Proc. Roy. Phys. Soc. Edin.*, vol. viii. p. 400.

from neritic* Plankton, which latter term includes surface organisms in waters near coninental and other coasts.† They would appear, however, on the whole, to prefer oceanic waters where the salinity of the water is relatively low, for in the very salt waters of the Red Sea, of the Mediterranean, and of the trade-wind regions of the Atlantic, although numerous, they are not apparently so abundant as in the less salt waters of the Pacific, Indian, Southern, or Polar Oceans. The tow-net experiments of the "Challenger" Expedition showed that those Radiolarians which secrete the heaviest shells and skeletons, as well as the whole legion of Phæodaria, were captured in greatest numbers when the nets were dragged a considerable distance beneath the surface, so that it is probable that many species live in the intermediate waters of the ocean where the temperature is as low as 50° or 40° F. Some species of Diatoms and Radiolarians are often met with in such great numbers that they form vast floating banks, fields, or zones, between which are lanes of water comparatively free from these organisms. We have referred to the banks of Diatoms in the Arctic and Antarctic Oceans and in the Arafura Sea. In 1880, in the Faroe Channel, the tow-nets were filled with Radiolarians, belonging to the genera: *Acanthometra*, *Xiphacantha*, *Dorataspis*, *Ethmosphæra*, *Heliosphæra*, *Rhizosphæra*, *Actinomma*, *Spongocyrtis*, *Thalassicolla*, *Calcaromma*, *Actinocyrtis*, *Amphilonche*, *Spongodiscus*, and *Thalassosphæra*—for weeks together; but two years later, in the same month, only a few of these organisms were captured, the surface waters being then chiefly occupied by vast numbers of *Doliolum*.

If we now turn to the remains of Diatoms and Radiolarians found in the marine deposits at the bottom of the ocean, we find that they are almost universally distributed. Radiolarian remains were observed in considerable abundance in more than two-thirds, and Diatoms in like abundance in more than one-half, of the samples of deep-sea deposits collected by the "Challenger," and a careful examination of large samples revealed the presence of these organisms in nearly every specimen of pelagic and terrigenous deposits. In the deep-sea deposits of the Atlantic, Radiolarians, Diatoms, and Sponge spicules, make up, on an average, about $1\frac{1}{2}$ per cent., in the Pacific

* Νηρίτης, son of Nereus (see Haeckel, *Plankton-Studien*, p. 22, Jena, 1890).

† Haeckel, *loc. cit.*

about 6 per cent., and in the Southern and Antarctic Oceans about 16 per cent., of the deposits. In some special regions, however, they play a much more important part in the formation of deep-sea deposits. There would appear to be a wide band or zone of Diatom Ooze surrounding the South Pole, between the latitude of 40° S. and the Antarctic Circle, covering about 10,880,000 square miles of the sea-bottom, in which the percentage of siliceous organisms is, on the average, about 50 per cent. of the whole deposit.

Again, in the central parts of the Pacific and Indian Oceans there are large areas of Radiolarian Ooze in the greatest depths, covering in all about 2,290,000 square miles of the earth's surface, in which the remains of siliceous organisms are estimated to make up nearly 60 per cent. of the whole deposit. In some Globigerina and Pteropod Oozes, as well as in some Red Clays and Blue Muds, there are in certain regions very few, if any, traces of these pelagic Diatoms and Radiolaria. It is somewhat difficult to account for their absence, for they are captured in the surface waters of these areas, although not in such great abundance as in the surface waters over regions where they make up a large part of the deposit at the sea-bottom. In some instances they appear to have been removed in solution, as will be pointed out later on; in others their presence may be masked by the relatively much more rapid accumulation of calcareous remains, of triturated pumice, or of land debris.

In our previous paper, when discussing the secretion of carbonate of lime by marine organisms, we found it impossible to accept the view that the lime was absorbed and secreted directly as carbonate, owing to the small amount of carbonate of lime in solution in sea-water—one part in 8000—and the enormous quantity of water that would consequently require to pass into the life circulation to permit its secretion were this the only source. We were able to show, we think successfully, that organisms may obtain their carbonate of lime from any of the lime salts in sea-water, by means of the changes produced by their effete or waste products on the constitution of the lime salts in solution, the whole of the lime present being in this way available for the formation of carbonate of lime shells. A similar difficulty with reference to the source of the silica is presented in the case of the silica-secreting organisms, for to obtain the

silica necessary for their shells and skeletons these organisms must pass an enormous quantity of sea-water through their bodies. No interpretation like that adopted for the carbonate of lime organisms is possible here, for silica is present in solution in sea-water only in one condition, and our own and the analyses of different authorities give only the merest traces of soluble silica in sea-water.

It will be seen, by reference to the accompanying Table, that the determinations of silica in sea-water by various authors can be

TABLE I.—*Silica in Various Sea Waters.*

Observer.	Locality.	Number of Determinations.	SiO_2 in grms. per litre.		SiO_2 in parts of Water.	
			Max.	Min.	Max.	Min.
Förchammer, . .	Atlantic, ...	12	0·1130	0·0690	9,090	14,880
Bibra, ...	Do., ...	2	none		...	...
Hunter, ...	Do. (S.W. of Ireland), . .	13	none		...	...
Anderson (Granton), ...	Do., ...	1	0·0020	...	513,500	...
Do. Do.,	Do. (bottom water 1760 fms.),	1	0·0040	...	256,600	...
Förchammer, . .	Baltic Sea, ...	2	0·0720	0·0270	14,000	37,260
Sass, ...	Do., ...	1	0·0179	...	56,200	...
Göbel, jun., . . .	Do., ...	4	0·0230	0·0005	43,740	2,012,000
C. Schmidt, . . .	Do., ...	1	0·0023	...	437,400	...
Do., . . .	Coast of Norway, . .	2	0·0172	0·0149	60,000	68,500
Figuer and Mialhe,	Havre, ...	1	0·0085	...	121,000	...
Clemm, ...	St George's Channel,	1	trace	...	...	...
Anderson (Granton), ...	North Sea, ...	2	0·0016	0·0006	640,000	1,700,000
Do. Do., . .	Shore at Granton, .	4	0·0010	0·0003	1,024,000	3,410,000
C. Schmidt, . . .	Arctic Ocean, . . .	1	0·0144	...	71,100	...
Anderson, ...	Mediterranean, . .	1	0·0074	...	139,000	...
Förchammer, . .	West Mediterranean,	4	0·0870	0·0800	11,820	12,900
Do., . .	Straits of Gibraltar, .	2	0·0930	0·0730	11,000	14,000
Do., . .	At Malta, ...	1	0·0800	...	12,900	...
Do., . .	East Mediterranean,	5	0·1380	0·0290	7,450	35,500
Vierthaler, . . .	Adriatic, ...	1	0·1100	...	9,340	...
Rotmet and Lefort,	Suez, ...	1	trace	...	...	...
C. Schmidt, . . .	Red Sea, ...	2	0·0052	0·0032	197,700	321,000
Do., . . .	Indian Ocean, . . .	3	0·0030	0·0021	342,300	490,000
Do., . . .	South China Sea, . .	1	0·0032	...	321,000	...

arranged into a maximum group, thirty in number, and a minimum group, twenty-three in number. In the maximum group many of the determinations include phosphates along with silicic acid, and it appears evident, from our own analyses, as well as from the great irregularity of these maximum results, that the waters were not filtered before analysis—two samples of the same water from the Adriatic, for example, gave respectively 0·110 and 0·237 grm. per litre. In the second or minimum group the waters have evidently been filtered before analysis, and the results exhibit a striking uni-

formity when compared with those of the maximum group. It will be seen that the analyses of the filtered waters show silicic acid is present either in traces or only in quantity equal to one part in from 220,000 to 460,000 parts of sea-water, or even in still more minute quantities.

The determinations made by us at the Scottish Marine Station with carefully-filtered waters from different parts of the ocean led to similar results. The amount of soluble silica was so minute that it was difficult to believe it to be the exclusive source from which Diatoms and Radiolarians procured the silica for their frustules and skeletons, the results showing only one part of soluble silica present in from 200,000 to 500,000 parts of sea-water.

In all attempts to determine the silicic acid, we filtered the sea-water through several folds of ashless filter-paper, or we added to it, in the cold, a solution of pure albumen, thereafter raising the liquid to a temperature of 212° F., so that the coagulated albumen which collected as a scum on the top of the boiling fluid carried with it any mechanically suspended matter present in the water. Even the ash from the apparently ashless filter may give rise to a profound error in the result, and in these determinations, in order to secure absolute accuracy, platinum vessels should be used.* The accurate determination of silicic acid in sea-water is complicated by another difficulty. This arises from the presence of fluorides, which in the ordinary methods for determining silicic acid would tend to form volatile fluoride of silicon, thus vitiating the results of the analyses. The results referred to above, showing the quantity of silicic acid in sea-water to amount to not more than one part in 200,000 to 500,000, were obtained by evaporating a weighed quantity of carefully-filtered sea-water to dryness with hydrochloric acid. The dried salts were drenched with hydrochloric acid and again heated to dryness, the insoluble residue left being taken as silicic acid. It is evident that in the presence of fluorides, if in sufficient amount, the whole of the silicic acid would be driven off, and pass away during the evaporation and subsequent drying and ignition.†

* The balance used by us was not very delicate; the results can only be relied on to the third place of decimals.

† Exp. (A). To determine this point we added silicic acid in a soluble form to a litre of artificial sea-water (which water was practically free from silicic acid),

Even when any loss of silicic acid which may occur from this source of error is taken into account, the amount of soluble silica in sea-water is too small to be quite certain that it is sufficient to supply all that is required by silica-secreting organisms.

Moreover, if we accept the fact that the sea receives the greater part of its silicic acid from the waters carried down to it by rivers in the form of soluble silicates, we should expect that such silicates would be decomposed by the salts of magnesium so abundantly present in sea-water, with the formation of silicate of magnesia. This substance we know, in the condition of steatite or talc, is so insoluble, that no appreciable amount is removed by solution in water, even in presence of free carbonic acid.* We have found, however,

the amount so added being 0·0342 grm., adding also 0·096 grm. of fluoride of sodium. The whole was then evaporated to dryness with hydrochloric acid, and the residue dried and drenched with hydrochloric acid, and again dried. The silicic acid determined in the insoluble residue showed that 80·4 per cent. of the whole silicic acid added had been thus recovered, only 19·6 per cent. being lost by the action of the fluoride. A similar experiment (B) was conducted with the same amount of silicic acid as in Experiment (A), but 0·960 grm., or ten times the amount of fluoride of sodium, was added to the same amount of artificial sea-water. This quantity gave a precipitate of fluoride of calcium with the lime salts of the sea-water, so that such an amount of fluorine could not be present in natural sea-water. The amount of silicic acid recovered in this instance was 67·5 per cent., the loss of silicic acid being 32·5 per cent. A third experiment (C) was made, in which a large excess of fluoride of sodium was again added, and the evaporation and drenching with hydrochloric acid repeated six or seven times in succession. It was then found that only 4 per cent. of the silicic acid added remained in the insoluble residue. These results would seem to show that even if sea-water contained as much silicic acid as one part in 50,000, and also as much fluoride as it could hold in solution, at least two-thirds of the silicic acid present in sea-water would be found by the methods ordinarily in use for silicic acid determination. Nothing like that quantity (1 in 50,000 parts) was ever found in our experiments. The third experiment (C) shows that the silicic acid may be carried away in a volatile condition, combined with fluorine, after repeated evaporations with hydrochloric acid and ignitings, so that the amount of silicic acid we have found in carefully-filtered sea-water must be correct within the limits of at least 20 per cent. (see Experiment A), thus making it according to these determinations less than one part in 250,000.

* Bischoff, *Chemical and Physical Geology*, vol. i. p. 3. Mr Alexander Johnstone, F.G.S., has proved experimentally that pure water, even when saturated with carbonic acid, has no solvent action on pure talc or steatite, but that sea-water has a slight but distinct effect in this direction equal to 1 part in 200,000. His results are also interesting as showing that silicate of magnesium once formed cannot be conveyed to any extent in a soluble condition by river water to the sea (*Proc. Roy. Soc. Edin.*, vol. xvi. pp. 172–175, 1889).

that silicate of magnesia, in an amorphous condition, is distinctly soluble in pure water, and also to a greater extent in sea-water.

To determine this we added pure silicate of soda to sea-water in the following proportions :—

Silicate of soda representing—

1 part	silicic acid	added to	1,000	parts	sea-water	produced a large precipitate.		
1 ,,	,,	,,	10,000	,,	,,	gave a distinct precipitate.		
1 ,,	,,	,,	20,000	,,	,,	,, precipitate after	24	hours.
1 ,,	,,	,,	30,000	,,	,,	,, ,, ,,	36	,,
1 ,,	,,	,,	40,000	,,	,,	,, ,, ,,	48	,,
1 ,,	,,	,,	50,000	,,	,,	,, ,, ,,	144	,,
1 ,,	,,	,,	100,000	,,	,,	,, ,, ,,	144	,,

These precipitates consisted principally of silicate of magnesia, silicic acid, and traces of silicate of lime ; so that we are justified in concluding that if alkaline silicates in proportion equal to 1 part of silicic acid in 100,000 parts of water were present, the whole would be removed in combination with magnesia and thrown out of solution. For the sake of argument, let us suppose that silicic acid did occur to this extent in sea-water, thus representing 0·01 grm. per litre, even this amount, taking it, we shall say, as a saturated solution of the most insoluble silicate known, is very much less than the amount of silicic acid found by the analysts whose results represent the maximum amount of that body found in sea-water (see Table I., p. 235). These experiments were repeated with pure water, to which chloride of magnesium was added together with pure silicate of soda. The results showed that amorphous or freshly-precipitated silicate of magnesia was less soluble in fresh than in sea water, thus leading us to assume that it could not be carried to the sea as such by rivers, as also that river water, rich in other magnesium salts, can hardly be supposed to carry soluble silicates to the sea.

A similar series of experiments were conducted with lime salts, but the amorphous silicate of lime so formed was found, in comparison with the silicate of magnesium, to be so soluble that it did not cause any precipitate above 1 part in 50,000 of water in twenty-four hours.

To vary these experiments, a weak solution of silicate of soda was exactly neutralised by means of hydrochloric acid ; an amount representing 1 grm. of soluble or colloid silicic acid was added to

1 litre of sea-water, the one-half of which was kept at a temperature of 40° and the other at 80° Fahr. Here apparently more silicic acid was retained in solution by the sea-water than in the former experiment with the alkaline silicate, and on determining the amount of silicic acid in the filtered sea-water after seventy-two hours, it was found that sea-water could hold up for that period 0·1346 grm. per litre, the precipitate consisting principally of silicic acid and silicate of magnesia. We think, however, that as a rule silicic acid must reach the ocean in the form of silicates.*

At this point it may be well to refer to the character of river water in its relation to the amount of silicic acid carried to the sea. From the analyses of forty-eight river waters given by Bischoff,† we find the average quantity of silicic acid present to amount to about 1 part in 100,000. But here the same source of error seems to have crept in, as is the case with the silicic acid determinations in sea-water, a certain number of analysts showing a maximum amount equal to 4·8 parts in 100,000, whilst others show minimum results equivalent to 0·01 part in 100,000. That this source of error is due to the presence of insoluble clay, is pretty well proved by the results of certain of the analyses. For instance, in those of the waters of the Maas, the amount of silica at Hocht is 2 parts in 100,000; at Pierrebleue, 1·04; and at Arensdonck, 0·28; clearly showing that the water had deposited insoluble siliceous matter or clay in its course to the sea. However this may be, it is certainly curious to note, taking the minimum results of these forty-eight analyses as representing the true amount of soluble silicic acid in river water, that we find it equivalent to 1 part of that body in 250,000 to

* A solution of silicate of soda was neutralised with carbonic acid, and an amount of this solution equal to 1 grm. of soluble or colloid silicic acid added to 1 litre of sea-water. A comparatively small precipitate resulted, and was found to consist of silicic acid and silicate of magnesia, with traces of lime. The clear liquid filtrate from this precipitate remained for a very long period perfectly clear, and only deposited a slight additional precipitate after standing more than fourteen days. The silicic acid was determined in the filtrate, and it was found that the amount of the precipitate corresponded with the carbonate of magnesia or lime which occurred in the water. Thus if soluble silicic acid in any circumstances be added to sea-water, we should expect only that portion thrown out that would thus combine with the alkaline constituents of the sea-water, the amount of alkaline constituents being always enormously in excess over that in which silicic acid could exist either in surface or bottom water.

† *Loc. cit.*, vol. i. pp. 76, 77.

400,000 parts of water—figures curiously corresponding to those representing the minimum determinations of soluble silica in sea-water by us (see Table I.).*

As was stated above, there are no means at our disposal to explain the elaboration of silica from salts by organisms, as in the case of the secretion of carbonate of lime from other calcium salts.† Silicic acid, if present at all in the ocean in a soluble form, can only occur in that one condition. Where then are we to look for the sources from which Diatoms, Radiolarians, Sponges, &c., obtain the silica necessary for their siliceous skeletons?

Early in the course of these investigations we were led to suspect that the pelagic siliceous organisms might, in part at least, obtain the silica for their frustules and skeletons from the clayey matter suspended mechanically in sea-water. It has been long known that the principal part of the fine clayey matter suspended in river water is

* Kyle, in his analyses of the water supplied to the city of Buenos Ayres, states that "the river Plate is in reality the estuary of the rivers Parana and Uruguay. It is characterised by its muddy appearance, and always contains in suspension a considerable amount of coloured clay." In the analyses which follow of the waters of the rivers Plate and Parana, this clay is represented as alumina and silica. From this it is evident that the waters were not filtered before analysis. On the other hand, looking at the analyses of the water of the river Uruguay, the analyst characterises it "as a very remarkable one, and probably one of the purest river waters in the world, containing rather less than four parts of solid matter per 100,000. Alumina is entirely absent, the noteworthy fact being that about 46 per cent. of the total solid matter consists of soluble silica not suspended as in the other two rivers. A small proportion exists probably as alkaline silicates, but the greater part is undoubtedly present as hydrated silicic acid." In these circumstances may be found an explanation of the petrifying properties attributed to the water of the Uruguay (*Chemical News*, vol. xxxviii. p. 28).

The abnormal quantity of free silicic acid present in these waters may be accounted for, either by the decomposition of felspar rocks by carbonic acid, or by the action of azo-humic acids referred to by Julien ("On the Geological Action of Humus Acids," *Proc. American Ass.*, vol. xxviii. p. 325) on silica itself. But, granted all that has been advanced as to the carriage of silicic acid as such in a soluble condition to the sea by rivers, as we have shown, when such water mixes with the sea there can be no possible accumulation of soluble silica over that of one part in from 50,000 to 100,000 parts of water. Julien, we think wrongly, urges that the humus acids may have the same action in sea-water that they have upon silica on land in the presence of fresh water; that a vast proportion of humus acids reaches the sea is undoubtedly the case, but immediately on mixing with salt-water the humus acid is thrown down either in combination with lime, magnesia, or alumina.

† See Murray and Irvine, "Coral Reefs and other Carbonate of Lime Formations in Modern Seas," *Proc. Roy. Soc. Edin.*, vol. xvii. pp. 79–109, 1890.

precipitated to the bottom when the river water mixes with the waters of the ocean.*

We have consequently made a large number of experiments (exceeding 100 determinations) bearing on this point. The following Table gives the results of a series of experiments with clayey matter suspended in sea-water of different salinities, and at different temperatures.

TABLE II.—*Amount of Clay remaining suspended in Sea-Waters of Various Densities, after being shaken up, and allowed to stand at rest, at Temperatures of* 40° *F. and* 80° *F. Results in grammes per Litre.*

α Temperature, 80° F.

		1025s	1026s	1027s	1028s
Time 24 hours, . .	Sea Clay	0·0038	0·0033	0·0033	0·0028
,, ,, ,, . .	Land ,,	0·0033	0·0023	0·0023	0·0023
,, 120 ,, . .	Sea ,,	0·0003	0·0003	0·0003	0·0003
,, ,, ,, . .	Land ,,	0·0003	0·0003	0·0003	0·0003

β Temperature, 40° to 50° F.

		1025s	1026s	1027s	1028s
Time 24 hours, . .	Sea Clay	0·0058	0·0063	0·0068	0·0068
,, ,, ,, . .	Land ,,	0·0058	0·0060	0·0068	0·0060
,, 106 ,, . .	Sea ,,	0·0013	0·0018	0·0018	0·0018
,, ,, ,, . .	Land ,,	0·0015	0·0013	0·0015	0·0013
,, 120 ,, . .	Sea ,,	0·0010	0·0010	0·0013	0·0015
,, ,, ,, . .	Land ,,	0·0010	0·0010	0·0010	0·0010

γ Temperature, 80° F.

	1000s	1005s·6	1010s	1015s	1020s	1025s	1028s
Time 24 hours,	0·0623	0·0048	0·0028	0·0020	0·0018	0·0018	0·0018
,, 96 ,,	0·0723	0·0028	0·0018	0·0013	0·0013	0·0010	0·0010

* Advantage is taken of this fact in the purification of muddy waters for domestic and manufacturing purposes by adding lime and alumina salts, which induce the separation of suspended matter and its subsidence (see Sidell in Humphreys and Abbot's *Report on the Mississippi*, Appendix A, No. 2, pp. 495 *et seq.*, 1876; Schultze, *Pogg. Ann.*, vol. 129, p. 366, 1866).

δ Temperature, 40° to 50° F.

	1000s	1005s·6	1010s	1015s	1020s	1025s	1028s
Time 6 hours,	...	0·0558	0·0568	0·0388	0·0388	0·0418	0·0333
,, 24 ,,	0·1215	0·0113	0·0073	0·0053	0·0053	0·0053	0·0053
,, 48 ,,	...	0·0048	0·0038	0·0025	0·0028	0·0031	0·0035
,, 72 ,,	...	0·0033	0·0018	0·0018	0·0013	0·0018	0·0018
,, 96 ,,	0·0658	0·0028	0·0013	0·0013	0·0013	0·0013	0·0013

ε Water (1024s) from shore at Granton.

After 24 hours at 80° F. contained 0·0083 grm.
,, ,, 50° F. ,, 0·0188 ,,

ζ Clay suspended in Salts of Sea Water.

Temperature 80° F.	$CaSO_4$	$MgCl_2$	$MgSO_4$	NaCl	K_2SO_4
Time 48 hours, . .	0·0013	0·0015	0·0023	0·0116	0·0563

It will be seen that with waters of all salinities above 1010 the great bulk of the heavier clayey matter is thrown down in the course of twenty-four hours, which is in harmony with the results of previous observers. There is, however, a small residuum which is held in suspension, even in waters of a salinity equal to 1028. The amount, it will be observed, varies with the temperature. At a temperature of 40° to 50° F., and a salinity of 1027, 0·0064 grm. per litre of clay remained in suspension at the end of twenty-four hours,* while, under the same condition as to time, at a temperature of 80° F., only 0·0033 grm. remained in suspension.† At the former temperature, 0·0018 grm. remained suspended at the end of 106 hours,‡ and at the latter only 0·0003 grm. at the end of 120 hours.§ It appears, then, that all the clay brought to the ocean by rivers is not precipitated on mixing with sea-water, but a very small quantity may be carried far and wide by ocean currents, the amount thus held

* = 27,500 tons per cubic mile of water.
† = 14,200 tons per cubic mile of water.
‡ = 7740 tons per cubic mile of water.
§ = 1300 tons per cubic mile of water.

in suspension by the sea-water depending largely on the temperature, and to a less extent on the salinity, being greater the lower the temperature and salinity.

To ascertain the amount of clayey matter in suspension in the open sea far from land, we procured large samples from the surface of the Atlantic, the Indian Ocean, Red Sea, the Mediterranean, the German Ocean, the Baltic Sea, and the Firth of Forth.* These waters were preserved in stoneware jars thoroughly cleaned and filled with the utmost care, so that no siliceous matter might be accidentally introduced. About 14 litres of sea-water were passed through a double ashless filter, and, after carefully washing the solid matter left on the filter to get rid of salts, the whole was burned, and the residue treated in a platinum vessel with pure boiling sulphuric acid,—the silicic acid, iron, and alumina were treated in the usual way. The results are exhibited in the following Table :—

TABLE III.—*Showing Amount of Mechanically-Suspended Silicates (Clay) present in Water of Different Seas.*

	In 14 Litres of Water.	Per Cubic Mile of Water.
I. Firth of Forth, 1 mile from shore, .	0·0259 grm.	8000 tons.
II. Atlantic Ocean, lat. 51° 20′, long. 31° W., ...	0·0052 ,,	1604 ,,
III. German Ocean, 30 miles E. of May Island,	0·0063 ,,	1946 ,,
IV. Mediterranean, centre of eastern basin, .	0·0065 ,,	2031 ,,
V. Baltic Sea, salinity 1005·5 . . .	0·0105 ,,	3200 ,,
VI. Red Sea, off Brothers Island, . .	0·0006 ,,	264 ,,
VII. Indian Ocean, lat. 15° 46′ N., long. 58° 51′ E., ...	0·0006 ,,	264 ,,

In the first determination (I.), Firth of Forth, the amount of silica in the clay, represented above, is about one-fourth what our minimum results show as present in a soluble condition in sea-water. In Baltic water (V.), salinity 1005, about one-eighth; in Atlantic, German Ocean, and Mediterranean waters (II., III. and IV.), about one-sixteenth, and in the Indian Ocean and Red Sea still less.

This seems to establish the fact that there is always a small

* We are indebted to Captains Thomas S. Knox and George Read, of the Anchor Line, for collecting the waters from the Mediterranean, Indian, and Atlantic Oceans.

quantity of silicate of alumina or clay present in sea-water, even at very great distances from land, and in the saltest and warmest waters. The above waters were taken from the surface; but, by a carefully-collected series of waters from different depths, it might be shown that the deeper and colder waters contained a greater proportion of this fine clayey matter than the surface ones, and it is at once apparent that waters taken near shore will contain more than those from far out at sea.

Bearing in mind the above facts, it is interesting to recall what was stated above as to distribution of siliceous organisms in the ocean, they being more abundant in shore waters or in waters of a low salinity and in cold waters—as, for instance, Diatoms in brackish waters and in those of the cold Southern and Polar Oceans, and Radiolaria in polar waters and in the West Pacific and Eastern Indian Oceans, where there is a relatively low salinity, as well as in deep intermediate waters where there is a low temperature. This would seem to indicate that in the ocean siliceous organisms are more abundant where there is most clayey matter in suspension in the sea-water.

With the view of gaining some information as to the conditions under which silica might be secreted by organisms, we instituted a number of experiments with Diatoms and other silica-secreting plants. A culture solution, representing the mineral food of plants according to Sachs' formula, was prepared, consisting of—

Distilled water, . .	2000 grms.	Sulphate of magnesia, .	1 grm.
Chloride of sodium,	1 ,,	Phosphate of lime, .	1 ,,
Nitrate of potash, .	2 ,,	Ferric chloride, . .	1 ,,
Sulphate of lime, .	1 ,,		

(A) Into a portion of this solution a minute patch of Diatoms (*Navicula*) was placed (in August 1890) with a small quantity of silicic acid in the form of jelly. In the course of seventeen days they grew most vigorously, the Diatoms increasing in great numbers —possessing the characteristic yellow-green colour of chlorophyll, giving off oxygen abundantly in sunlight, and moving about with the peculiar motion of these organisms. From this patch of Diatoms we obtained the material for the following experiments.

(B) A small quantity of living Diatoms from (A) was carefully washed so as to remove all traces of silicic acid or soluble silicates,

and transferred to a fresh portion of culture solution pure and simple. For a time the plants continued to live, but their increase was trifling, and after twenty-seven days they presented the appearance of dead organisms, being deprived of their green colour, ceasing to give off oxygen in sunlight, and were without motion.

(C) Another patch of (A) carefully washed was placed in culture solution, into which a quantity of very finely-levigated clay from the fields was introduced. (This clay by careful washing was entirely freed from any soluble matter.) After a short time the whole clayey matter became entirely altered in appearance, forming a sticky matted-like substance, from which in sunlight oxygen was freely given off, and which under the microscope showed an enormous growth of Diatoms, having the characteristic yellow-green colour of the healthy algæ. This experiment has been continued for a number of months, and the results obtained, so far as the development of Diatoms is concerned, has been so extraordinary that we have examined with the utmost care any possible source from which they might derive silica (apparently necessary to their life functions), other than from the clay which was added.*

The experiment (B) seemed to prove conclusively enough that siliceous plants cannot obtain silica in sufficient quantity from the glass vessels used for that experiment. We were also suspicious that atmospheric dust might have provided a certain amount of siliceous nourishment, but the fact that the Diatoms in experiment (B) had been unable to live seemed to us to prove that neither from the glass vessels nor from atmospheric dust could they obtain, *under the*

* Johann Nave, writing of Diatoms, remarks that these Algæ abound wherever water collects, from the sea to the smallest puddle on the way-side, and are generally associated with clay or mud. Gerstenbergh's plan for the propagation of Diatoms is instructive. He spreads the mud (containing Diatoms) on a plate or shallow dish, and exposes it to the full light of the sun. Stimulated by its rays, the plants begin to multiply rapidly, and on removal those left in the mud may be stimulated into active production by repeating the same process. By degrees the vitality of the little plant exhausts itself, and it is necessary to revive their vegetative powers. This may be accomplished by creating an artificial spring and winter. You have only to allow the water to evaporate, and the mud to become nearly, but not quite, dry, when, on fresh water being poured over it, vegetation commences anew. In this way gatherings originally poor may be made to yield an abundant supply of Diatomacea.

careful conditions of our experiments, sufficient silica for vigorous growth. On placing a small portion of the matted sludgy matter under the microscope, it was interesting to notice that all round the outside, and even piercing into the very centre of the mineral matter composing the mud, there were living Diatoms in great abundance, whilst in the clearer field of the microscope free from clay, only a very few were detected floating about. These experiments seem to point to the conclusion that these organisms are in the process of growth able to obtain their silica from (otherwise) insoluble compounds of silicate of alumina.

(D) A patch of (A) was introduced (August 1890) into culture solution containing silicate of lime. The result here was an abundant growth of Diatoms.

(E) A patch of (A) was introduced (August 1890) into culture solution containing pure amorphous silica. A very few seemed to have lived, but the major portion had died by December 15, 1890.

(F) A patch of (A) was introduced (August 1890) into culture solution containing Diatom Ooze, and when examined shortly afterwards there seemed to be no growth, but subsequently (December 15) a considerable mass of living Diatoms was observed. This may be due to the soluble silica present in Diatom Ooze, but of course such a source of silicic acid for surface Diatoms is out of the question. However, Sponges may obtain their silicic acid in part in this manner.

Take now the case of land plants growing in a virgin soil, consisting of decomposing rocks, sand, clay, and salts of lime, potash, and so on, or in a barren soil, from which, by repeated cropping, all the soluble food salts have been extracted, but to which manure is added to replace the salts represented in the culture solution used in our experiments. In either case we have bulky crops grown, and on examining the ash left on burning the grain or straw we find large quantities of silicic acid which has been absorbed, as is shown by the following Table:—

TABLE IV.

The ash of	wheat	straw	contains	73·57	per cent.	silicic acid.
,,	barley	,,	,,	32·73	,,	,,
,,	oat	,,	,,	38·48	,,	,,
,,	hay	,,	,,	53·43	,,	,,

Here we find silicic acid always present, and in many cases bulking very largely of the whole amount of the ash left on incinerating the plants.

On looking at the analyses of such soils, we find a very large proportion of their constituents to consist of silicic acid, but in the insoluble form of sand, or in chemical combination with alumina as insoluble clay.

In the drainage water from good arable land, the amount of silica found amounts only to 1 part in 100,000. There must therefore be processes at work by which a plant can render soluble and make available the silicic acid of the soil, from which its roots obtain this in common with other mineral food. It has frequently been pointed out * that when polished slabs of marble, dolomite, or apatite were buried in pure sand, in which seeds were planted, wherever the roots of the plants reached the slabs corrosion of the surface took place, which is explained by stating that the fine rootlets secrete acids having a solvent and disintegrating action on the lime-bearing rocks. The rootlets have in all probability a similar effect on siliceous rocks. In the case of what we consider eminently siliceous plants, the silicic acid absorbed from the soil and secreted on the outer cell-walls of the stems and in the joints must, it appears to us, have been so obtained. The clay, or even the sand grains, has been no doubt rendered soluble by plant action, for we have seen that no ordinary soil contains soluble silicic acid in the least degree equal to what is required for the healthy life of such plants as produce siliceous coatings. So far as we know, some plants usually containing silicic acid can be grown to vigorous and complete development under conditions in which they are entirely deprived of silicic acid; and granting that silicic acid does not appear to be necessary for their nutrition, yet we find it present in most plants, just in the same way as carbonate of lime, although not necessary for the nutrition of animals and plants, yet is always present in Foraminifera, Algæ, &c., † where we find it always associated as part of the body structure.

At one time agriculturists supposed that by adding soluble silicates to the soil, the stems of cereals would be so strengthened that

* Sachs' *Physiology of Plants*, pp. 262, 263.

† See Pouchet and Chabry, "L'eau de mer artificielle comme agent tératogénique," *Journ. de l'Anatomie*, 1889, pp. 289–307.

the laying of crops by stormy weather would be prevented. The result proved that no more silicic acid was secreted by plants under these conditions than when no such addition was made. Here we have apparently proof that the source of silicic acid in plants lies beyond any question of soluble silica present in the soil. As to the secretion of silicic acid by marine plants and animals, we think it is unnecessary to formulate any elaborate chemical theory to account for its absorption and secretion. There can be but little doubt that marine plants and animals have the power of decomposing the insoluble silicate of alumina, or clay, which we have seen occurs in all sea-waters we have examined. The experiments we have been able to perform with Diatoms in the carefully-washed field clay and pure water, appear to indicate what takes place on such an enormous scale in nature, and to point to suspended clay as a true source from which siliceous organisms derive their silica.

In the case of the secretion of silicic acid by Sponges, we may have another condition of things, also capable of explanation in a somewhat similar way. These Sponges grow in a muddy soil, and are provided with spicules, fixing them firmly in the deposit where decomposing organic matter is abundant, under the influence of which alkaline sulphides are continually being formed (by the deoxidation of the alkaline sulphates of sea-water). These sulphides may, acting locally, decompose the clay or silicate of alumina, setting free soluble silicic acid to be absorbed and stored up by the Sponges. It is not impossible that Diatoms, floating as they do near the surface of the water, may also receive silica in this manner, the organic matter present in the floating clay indirectly causing solution of silicic acid. The presence of alumina in a quantity of Diatoms obtained in the Antarctic Ocean seems to point not only to the original presence of clay in the water, but its subsequent decomposition by these algæ.

There is also distinct solution of silicic acid when muds consisting of the remains of calcareous and siliceous organisms are acted upon by sea-water, as shown by the following experiments. A portion of mixed Diatom and Globigerina Oozes was placed in a litre of sea-water and some mussel flesh added, so as to obtain the conditions attending decomposing organic matter on an ocean floor consisting of these mixed muds. After a week's exposure, during which time

the organic matter had become putrid, the water was carefully filtered from the sediment, and the silicic acid determined in the filtrate. The amount found was equal to 0·025 grm. per litre, or, according to the amount of water, 1 part of silica had been dissolved from the Diatom Ooze in 41,000 parts of sea-water. This action of silicic acid in decomposing carbonate of lime was further proved by exposing 2 grms. of the two oozes to boiling water for half an hour, the amount of silicic acid present in a soluble condition after that period amounting to 0·014, or 1 in 80,000 of water. To check this result, and at the same time to determine whether the decomposing action of silicic acid upon carbonate of lime was continuous, a portion of the mixed oozes was heated with successive quantities of sea-water, when it was found that this action was constant. Thus, in a mixture of 89·42 per cent. of calcareous organisms and 10·58 per cent. of siliceous organisms, the amount of silica was reduced, by 25 successive litres of sea-water, from 10·58 to 3·47 per cent., so that 67 per cent. of the silica present was removed.*

On looking at the Tables showing the amount of suspended clay in sea-water (see pp. 241 and 242), and comparing the amount with the soluble silica or silicates in sea-water, it is to be observed that the maximum amount of silica found is much larger than that present as suspended clay. In the actual determinations of this body in the seven waters (shown in Table III., p. 243), the amount of clay found in these waters ranges from 264 to 8000 tons per cubic mile of water, thus roughly representing from 132 to 4000 tons of silica per cubic mile; whilst soluble silica, by the analysts' results we have quoted, appears at a much higher figure.

* In this connection Julien states ("On the Geological Action of Humus Acids," *Proc. Amer. Ass.*, vol. xxviii. p. 359)—"Considerable evidence now exists that a substance corresponding to humus, simply in its yield of acid solvents of lime, oxides of iron, manganese, &c., enters universally into the constitution of the layer of ooze upon the bottom of the ocean. Its exact composition has never yet been determined; but it may be suspected that it resembles that of glairine, especially in its high content of silica. As it has resulted from the continuous decomposition of the cellulose membranes of the diatomaceæ, &c., and of the gelatinous sarcode of the radiolaria, spongiæ, and foraminifera, which may be there living or deposited by subsidence from the surface, its composition must differ widely from that of the humus of subaërial eremacausis, in its large proportion of water and nitrogen and in its poverty in carbon. It must thus present the most favourable conditions for rapid dissociation."

In either case, without doubt the amount found is sufficient to account for the growth and accumulation of siliceous organisms in modern seas; but a moment's consideration will show that, by adopting the view that siliceous organisms obtain their siliceous matter also from insoluble matter floating in the water, we can understand to some extent their distribution in the ocean, and how they may obtain what to them is a vast local supply (close at hand) without being required to deal with an enormous quantity of liquid containing but minute traces of silica.* To exemplify what we mean, take, for example, an animal requiring, say, 1 lb. of solid food per day, this is quickly assimilated with the assistance of a *small* quantity of water; but if we suppose this same amount of solid food dissolved in from 250,000 to 300,000 times its weight of water, we are unable to conceive the possibility of the animal assimilating enough of the solid nutriment contained in this mass of liquid to sustain life.

In a future paper we hope to give further results of experiments now in progress on the subjects treated of in this paper.

In the analyses and determinations referred to in this communication we have been assisted throughout by Mr W. S. Anderson, Chemist at the Scottish Marine Station, Granton, and we desire to thank him for the great attention he has given to all the experiments.

* The abstraction of silicic acid from silicate of alumina will, of course, necessitate that an equivalent amount of alumina should be accounted for. Doubtless this passes into solution, for in all the sea-waters examined by us, after a most careful filtration, alumina has been found in solution (see also Dittmar's Report, *Phys. Chem. Chall. Exp.*, part i.)

A New Method for the Estimating the Specific Gravity of the Blood. By John Berry Haycraft, M.D., D.Sc.

(*Physiological Laboratory, University of Edinburgh.*)

(Read January 19, 1891.)

The method of Roy for determining the specific gravity of the blood is a very excellent one, and is capable of yielding sufficiently accurate results. Over thirty bottles containing mixtures of glycerine and water of different specific gravity, ranging from 1·030 to 1·070, are used for the estimation, and a drop of blood to be tested is placed in a sample of one of these fluids. If the drop sinks it is heavier, if it floats it has a lower specific gravity, and then another drop of the same blood is tested until by a few experiments the exact specific gravity is determined.

It might be imagined that this method is more difficult to carry out than it really is, and that it requires many attempts on the part of the experimenter, and the loss of much blood, before the specific gravity is finally settled. This is no doubt true in the case of a patient examined for the first time, but afterwards, knowing beforehand what the specific gravity is likely to be, it is easy, with one or two trials, to find out if any change in the specific gravity has occurred.

The chief objection to the method is, however, the cumbrous nature of the apparatus required, which would render it useless for the requirements of private practice, although undoubtedly of much value in the Hospital and Laboratory.

The method I venture to introduce has this advantage that the apparatus used is quite portable, requiring no more room than the space occupied by a small pocket case. The method is accurate, requires only a single drop of blood, and, moreover, it is perhaps more quickly done than that of Roy.

Two mixtures of benzyl chloride (sp. gr. 1·100) and toluol (sp. gr. 0·8706) are made, one (A) having a specific gravity of 1·070, and the other (B) having a specific gravity of 1·020. With a cubic centimetre pipette graduated to $\frac{1}{100}$th c.cm., one c.cm. of (A) is

measured off into a glass tube, and the drop of blood to be tested is allowed to flow into the tube as well. The drop of blood does not mix with the solution, having a different surface tension from it, and floats on its surface as a tiny red globule. The graduated pipette is now filled with solution (B) and this is allowed to run slowly into the mixing tube, shaking after each addition. As (B) flows in, the specific gravity of the mixture is lowered, and after each addition and shake the red globule returns more and more slowly to the surface. At last it neither tends to rise nor sink, and the mixture now has the specific gravity of the blood itself. The specific gravity of the mixture can readily be calculated, or found from the table attached to the apparatus made by Mr Fraser, Lothian Street. Suppose 0·5 cc. of (B) has been added, the total weight of the fluid divided by its volume will give the specific gravity of the mixture.

$$\begin{array}{lr} 1 \text{ cc. at sp. gr. } 1070 = & 1070 \\ \cdot 5 \text{ cc. at sp. gr. } 1020 = & 510 \\ \hline 1{\cdot}5)\ & 1580 \\ \hline & 1053 \end{array}$$

As the mixtures of benzyl chloride and toluol expand with heat they will vary in their specific gravity, so that a correction for temperature must be made if exactitude is required. The solutions (A) and (B) are prepared at the temperature of 15°·6 Centigrade or 60° F. and if the temperature of the room in which the experiment is made is also 60° F. no correction will be needed. If, however, the temperature is higher than 60° F. the specific gravity of the fluids will be lower, and this fall of specific gravity will be at the rate of 1° for every 2° F.

Example

$$\begin{array}{lr} 1 \text{ cc. of (A) at } 1070 = & 1070 \\ \cdot 5 \text{ cc. of (B) at } 1020 = & 510 \\ \hline 1{\cdot}5)\ & 1580 \\ \hline & 1053 \end{array}$$

Temperature of room 66° F., therefore 3° * must be subtracted the real specific gravity of the mixture (and therefore of the blood) being 1·050 at that temperature.

* The more accurate allowance for temperature is ·88° sp. gr. for every 2° F. of temperature above 60°. For all ordinary purposes 1° sp. gr. is sufficiently accurate and more easy to calculate, and hence that figure is given in the text.

My first attempt to estimate the specific gravity of blood was by quite another method. While watching a globule of blood slowly descend in a cylindrical vessel filled with oil, it occurred to me that by using drops of the same size, their specific gravity could easily be determined, for the higher their specific gravity the quicker would they fall. By the rate of fall, I found that the specific gravity could be determined with the greatest accuracy, but inasmuch as the viscosity of the oil, and therefore the rate of fall varies with the temperature, this must either remain constant or a correction made for it. As the viscosity varies considerably with even small changes of temperature I abandoned the method, as one incapable of clinical application, though it is, I find, highly to be recommended for laboratory purposes, where the temperature factor can be kept strictly under control. Having spent some time on this method I did not like to relinquish the subject, and the plan already described in this paper was worked out. It occurred to me that if I could obtain two fluids, both of which had a different surface tension from blood, one of which procured a higher, the other a lower specific gravity than blood itself, I could mix them until I hit off the exact specific gravity of any particular drop I might wish to examine. This is of course the principle of the method already detailed in this paper, but I was for some time unable to carry it out in practice, more especially as such fluids must be very mobile in order readily to mix with each other, and mobile fluids of high specific gravity are not very numerous. I first tried mixtures of chloroform and paraffin, one mixture having the sp. gr. 1·070, and the other sp. gr. 1·020. This plan did not succeed at all, for the mixture affects the density of the blood itself, a globule of blood, say of slightly lighter specific gravity than a given mixture of chloroform and paraffin, on its first immersion floating on the surface, but after a few seconds acquiring density and sinking in the fluid. I then tried mixtures of chloroform and toluol (chloroform, sp. gr. 1·498 ; toluol, sp. gr. 0·8706), and this time with success, the specific gravity of the blood remaining constant in the mixture. This method succeeds admirably, but the mixtures are apt to lose specific gravity on keeping, for the chloroform is very volatile, boiling at 61° C. I then sought for another mobile fluid having a higher specific gravity and a high

boiling-point. After one or two trials I used benzyl chloride, $C_6H_5CH_2CL$, having a specific gravity of 1·100, and a boiling-point 178° C. The only objection to this is its irritating vapour. It is well not to allow any of the fumes to get into the eyes, or somewhat painful smarting will result.

On the Estimation of Uric Acid in the Urine. A Reply to Criticisms upon the Silver Method. By John Berry Haycraft, M.D., D.Sc.

(*Physiological Laboratory, University of Edinburgh.*)

(Read February 16, 1891.)

(*Abstract.*)

I published in the *Brit. Med. Jour.*, December 12, 1885, a method invented by me for the easy and yet accurate estimation of uric acid. The method consists in precipitating the uric acid as a silver salt, estimating the silver, and calculating the uric acid from the silver (168 uric acid to 108 silver). As no process was then invented which had itself been tested, except as Salkowski's, by the side of others acknowledged to be inexact, I did all my work with weighed quantities of uric acid, and tested my process—the only straightforward way of working—by adding known quantities of uric acid to one of two samples of a urine, and finding as a result of my estimations of the uric acid in the two samples practically the same difference as the weight of acid added. Hermann confirms my work (*Zeitsch. f. physiol. Chemie*, Bd. xii. s. 496), and Czapek, working with Professor Huppert, proposes a modification of my method, while Camerer's results (*Zeitsch. f. Biologie*, Bd. xxvii. s. 113) run on parallel lines. My results have been adversely criticised by Salkowski, who still maintains that uric acid and silver do not combine in a definite ratio. This observer published in 1872 twelve analyses, which show, according to his belief, that there is no constancy in the proportion between the silver and uric acid, and in 1889 he again affirms the same thing, bringing forward in proof of his assertion some dozen analyses made by his colleague Professor Jolin and himself. I was for some time unwilling to take up the controversy where Professor Salkowski had left it, for, certain of the care with which my own work had been done, I was quite willing to let the matter be settled by other and less prejudiced persons, especially as such seemed willing enough to undertake the task. As, however, my method had been widely used, especially for clinical purposes, and

as I had frequently to answer queries concerning its accuracy, I felt it my duty carefully to examine once more the whole question, and if there was any doubt about it, at once to set that doubt at rest. I was I confess agreeably surprised to find that Professor Salkowski had made a slight mistake, which when rectified places his own results and mine in complete accord. In order to make this point quite clear I will venture to reproduce Professor Salkowski's results, arranging his analyses in order, beginning with the one having the least uric acid.

Salkowski's first Table (1892).

No.	1 Silver obtained.	2 Uric acid reckoned from 1.	3 Uric acid obtained.	4 Difference in mgrms.	5 Ratio between silver and uric acid.
1	·029	·045	·033	−12	4·1 : 3
2	·035	·054	·040	−14	4·09 : 3
3	·037	·057	·042	−15	4·2 : 3
4	·045	·070	·056	−14	3·71 : 3
5	·046	·071	·051	−20	4·03 : 3
6	·049	·077	·056	−21	4·02 : 3
7	·050	·078	·067	−11	3·43 : 3
8	·051	·079	·100	+21	2·24 : 3
9	·054	·084	·070	−14	3·36 : 3
10	·060	·094	·083	−11	3·63 : 3
11	·064	·100	·088	−12	3·41 : 3
12	·073	·114	·086	−28	3·96 : 3

I think No. 8 is evidently a spoilt analysis, for no similar result is ever again to be found in the tables of Salkowski, Jolin, Hermann, or Czapek, and the last, urine No. 12, must be considered under the head of "urine saturated with uric acid." Such urines, and Czapek estimated some of these, stand by themselves, and probably require dilution before the analysis is made. Omitting these two cases, and arranging the results as I have done, it is evident that there is, in each case, an excess of the uric acid estimated from the silver over that actually found by Salkowski's own process of about 14 mgrms. This difference is as constant as one can expect, for Jolin and Salkowski, in performing two check analyses of the uric acid, in one and the same urine, by one and the same process, fail to get them then to coincide by 3 or 4 mgrms. What Salkowski

proves, therefore, is that by his method about 14 mgrms. less uric acid are found than by the silver calculation. The mistake he fell into in interpreting his results will be obvious on referring to column 5 of his table. He here calculates the ratio between the silver and uric acid found by his method and does not find it constant. The reason is very obvious, for in the weaker urines the loss of 14 mgrms. will be comparatively a heavy loss, making the ratio of the uric acid to the silver low, while in the stronger urines the loss will be less felt. A glance at the table will show this, for the silver in the upper part of the table is say 4·1 to 3, while in the lower part it sinks to say 3·4 to 3. The loss of a pound is much to a poor man, but will not inconvenience a rich one, because it bears a small ratio to the sum that he possesses.

In Jolin and Salkowski's recent paper the same error is repeated without discovery, the table of estimation they give showing still more forcibly a "constant difference" as a result of their estimations. In the last two pages of his article this is shown very forcibly in the case of two final experiments made by Salkowski, who estimates both the silver and the uric acid (by his method) in one and the same urine :—

No.	Uric Acid reckoned from the Silver.	Uric Acid directly estimated (Salkowski).	Difference.	Ratio between Silver and Uric Acid.
1	·0756	·0556	19·1	3·99 : 3
2	·0938	·0757	18·1	3·66 : 3

He says "Das Æquivalentverhältniss zwischen Harnsäure und silber berechnet sich. Aus Versuch 1 = 3 : 3·99 aus Versuch ii. 3 : 3·66. Auch diese Bestimmungen bestätigen, also lediglich meine früheren Angaben. It is obvious that the existence of a constant difference of about 19 mgrms. (more urine was used than in this case, hence the greater deficit) was all he really proves, and this constant deficit tells most in the case of the weaker urine. Salkowski would not have misinterpreted his results had he arranged them with sufficient care or put in a column of differences which I have taken the liberty of adding. His results are therefore valuable

evidence in favour of the silver process, for a constant difference such as he obtains would not be possible were the compound (we will call it urate of silver) of unfixed and varying composition, and therefore his own results prove the proposition he intended to destroy.

The constant difference of 14 mgrms. is due, at any rate in part, to the imperfections of his own method, which he had never taken the trouble to test, merely comparing his results with those obtained by the unexact method of Heintz. This difference has been reduced to within the limits of manipulative error by Hermann and Czapek, when comparing the silver method with the method introduced by Ludwig.

Mr Gossage has also criticised my method on the same grounds as Salkowski, but I am afraid that his results must suffer a totally different explanation. He gives five estimations, in which he obtains the uric acid by the silver method and by Salkowski's method. His results may therefore strictly be compared with the exactly similar ones of Salkowski and Jolin. His average difference is 32 mgrms., which is more than the extreme difference obtained by the other chemists (28 mgrms.). If we accept the results of Salkowski and Jolin as trustworthy we are forced to look upon Mr Gossage's analyses as untrustworthy, and indeed his least manipulative error is greater than the greatest ever quoted by them. (For a full discussion of this question see a paper appearing in the next number of the *Zeitschrift f. physiol. Chemie*).

On a Method of Observing and Counting the Number of Water Particles in a Fog. By John Aitken, Esq.

(Read May 4, 1891.)

The phenomena known as haze, fog, mist, and rain are in a general way but the successive development of the same process, and the line which divides the one from the other is very indefinite. Dust in the atmosphere produces a haze, and the thickness of a haze of this kind depends principally on the amount of dust present when the relative humidity of the atmosphere is very low. But as the humidity increases the effect of the vapour increases also; the dust particles attract the water vapour which becomes deposited on them, thus increasing their size and their hazing effect, till at last when the air is nearly saturated it becomes very thick, and forms what we call a fog; when in this condition, the thickness of the atmosphere depends principally on the degree of saturation. Between the haze and the fog, however, there is no recognised distinction in kind, it is principally one of degree. After the air is saturated and the conditions are such as to tend to cause supersaturation, then a change takes place in the condensation. A few of the dust particles have water deposited on them, and after a time they grow and become little drops of water, in which the original dust nucleus bears a very small proportion to the total weight. At this stage it is still called a fog, but after more water is deposited on the small drops they grow and become what is known as mist, and when the mist drops combine and fall they are called rain-drops.

The instrument to be described will, it is hoped, in addition to enabling us to count the water drops, also give us a means of finding by observation the boundary line between a dry fog and a wet one, the latter being the name often given to the first stages in the formation of a mist, when the condensation is taking place at the level of the observer. At present two forms of apparatus are being developed for observing these water particles. The first and simplest is an instrument for observing whether there are any water particles in

the fog or not, that is, for determining whether it is a wet or a dry fog. This instrument can also be used for counting the number of drops which fall on a given area in a given time. It might be thought it would be quite unnecessary to use an instrument for telling us whether there are any water drops in the fog or not; because if there are any drops in it, they will be falling, and will wet all exposed surfaces, so that a piece of mirror would be all that would be necessary for the purpose. Such, however, is not the case. I have found in many fogs when all exposed surfaces were quite dry, that there were great quantities of water drops in the air and falling on all exposed surfaces. These drops, however, are so extremely small they are invisible under ordinary conditions, and being so small they rapidly evaporate, as all exposed surfaces are generally more or less heated by radiation during the day.

The plan I have adopted for observing these drops is the same as that used for observing the artificially made drops in the "Pocket Dust-Counter," described in a previous communication.* The new instrument consists of a glass micrometer divided into squares of a known size, a spot-mirror for illuminating the stage, and a strong lens or a microscope for observing the drops on the stages. The space between the micrometer and the lens is open, so that the air passes freely over the stage, and the drops that fall on its surface are easily seen. These drops are very small; as yet I have not had an opportunity of measuring them. They of course vary greatly in size, and many of them even when spread on the glass are not more than 0·05 mm. In observing these drops the attention requires to be confined to a limited area of the stage, as many of the drops rapidly evaporate, some almost as soon as they touch the glass, whilst the larger ones remain a few seconds. A square of 1 mm. is rather small an area, but one of $\frac{1}{16}$, or $\frac{1}{20}$ cm. does very well when working with a magnifying lens.

The following are samples of the results obtained when working with this instrument. On the 19th February 1891, at 10 A.M., the fog was so thick that objects beyond 100 yards were quite invisible. The surfaces of bodies exposed in the open air were dry. On this occasion the number of drops falling per minute varied greatly from time to time. The highest number observed

* *Proc. Roy. Soc. Edin.*, vol. xviii.

was 30 drops per min. per sq. mm., that is 3000 per sq. cm., or 19,350 per square inch per min. This high number never lasted for long, and in the intervals the number fell as low as 300 per sq. cm., or to one-tenth; the temperature at the time was 29°. Two days later, that is on the 21st of February, the air was again very foggy, about the same thickness as it was on the 19th at 10 A.M., and all exposed surfaces were dry; the number counted was 13 per sq. mm. per min., that is 1300 per sq. cm. or 8385 per sq. in. per min. This number remained fairly constant on this occasion, and slowly diminished as the fog cleared away. The temperature at the time was 31°. On both of these occasions the temperature had not risen more than $\frac{1}{2}$° above the night minimum. The number of dust particles in the air was also counted on these occasions, and on both days the number was very high, varying from 45,000 to 80,000 per c.c.

The number of water particles in a fog, as given by these observations, seems to be very large, and it is difficult to imagine how they evaporate so quickly that exposed surfaces are not wetted by them. It must, however, be remembered that they are very small, so small that they are not felt falling on the hands or face of the observer. Indeed, it is probable they never touch the skin. These fog drops are very similar in size to the little drops artificially produced in the "Dust-counter," and it is found that, if the stage of the "Dust-counter" is slightly heated, the drops never reach its surface, but are evaporated in the slightly heated layer of air over it.

If we knew the size of these drops we might be able to calculate the velocity of their fall, and from that obtain the number per given volume of air. As it would be more satisfactory to obtain this number from direct observation, the second form of the instrument has been designed. It is constructed on the same principle as the other one, but an arrangement is made by means of which the number of particles that fall from a known height are counted. My first attempts in this direction were not satisfactory, owing to using a magnifying lens for observing. This limited the height of air out of which the drops fell to little more than 1 cm. Another instrument has since been constructed in which this difficulty is overcome. In place of a short focussed lens, a low power microscope is used. This enables us to get easily 5 cm. of air over the stage.

In order to find the number of drops in this height of air the following plan has been adopted. Underneath and concentric with the microscope is mounted a tube 5 cm. long and 4 cm. diameter. This tube is provided with a bottom and a cover; these are both fixed to an axis parallel with the axis of the tube, so that by turning a handle both top and bottom can be slid sideways, and the tube closed or opened at top and bottom simultaneously, when desired. In the cover is a small opening corresponding to the lens of the microscope, and in the centre of the bottom is fixed a micrometer illuminated by a spot-mirror. When the top and bottom are turned aside the tube is open at both ends, and the air can circulate freely through it. On quickly turning the handle both top and bottom are closed, and the micrometer by the same movement is brought under the microscope, and all the drops that fall out of the 5 cm. of air over it are counted on a known area.

This instrument was only completed just when the fogs were about over for a season, and no satisfactory readings have been as yet obtained. It was, however, thought advisable to give this preliminary note at present, as the season for fogs has gone for a time, and it will give an opportunity for any one wishing to make observations in this way being prepared for the coming season.

It may be mentioned that the instrument first described, may be found useful for observing the larger particles of dust in the atmosphere. If it is exposed anywhere with the stage horizontal, the dust that settles on the glass can be distinctly seen with the lens. If the spot-mirror is applied to a microscope it gives an illumination very suitable for examining the smaller particles of dust. The very small particles, which are quite invisible under the ordinary form of illumination, shine out brilliantly when illuminated by the spot-mirror. The spot-mirror has also been found useful in the microscopic examination of delicate objects other than dust particles.

On an Optical Proof of the Existence of Suspended Matter in Flames. By Sir G. G. Stokes, Bart., F.R.S. (*In a letter to Professor Tait.*)

(Read June 15, 1891.)

8 Belgrave Crescent,
Edinburgh, June 13, 1891.

Dear Professor Tait,—I write to put on paper an account of the observation I mentioned to you to-night, in case you should think it worth communicating to the Royal Society of Edinburgh.

In the course of last summer I was led, in connection with some questions about lighthouses, to pass a beam of sunlight, condensed by a lens, through the flame of a candle. I noticed that where the cone of rays cut the luminous envelope there were two patches of light brighter than the general flame, which were evidently due to sunlight scattered by matter in the envelope which was in a state of suspension. The patches corresponded in area to the intersection of the double cone by the envelope, and their thickness was, I may say, insensibly small. Within the envelope, as well as outside, there was none of this scattering. The patches were made more conspicuous by viewing the whole through a cell with an ammoniacal solution of a salt of copper, or through a blue glass coloured by cobalt. In the former case the light from the flame was more weakened than the scattered light, which was richer in rays of high refrangibility; in the latter case the patches were distinguished by a difference of colour, the patches being blue, while the flame (with a suitable thickness of blue glass) was purplish. The light of the patches exhibited the polarisation of light scattered by fine particles —that is to say, when viewed in a direction perpendicular to the incident light it was polarised in a plane passing through the beam and the line of sight.

When the beam was passed through the blue base of the flame there was no scattered light. A luminous gas flame showed the patches indicating scattered light like the flame of a candle, but less copiously. They were not seen in a Bunsen flame or in the flame of alcohol, but were well seen in the luminous flame of ether.

When a glass jar was inverted over burning ether, the blue part, which does not show scattered light, extended higher till, just before the flame went out, the luminous part disappeared altogether. A Bunsen flame, fed with chloride of sodium, did not show the phenomenon, though the flame was fairly luminous.

The phenomenon shows very prettily the separation of carbon (associated, it may be, with some hydrogen) in the flame, and at the same time the extreme thinness of the layer which this forms. It shows, too, the mode of separation of the carbon, namely, that it is due to the action of heat on the volatile hydrocarbon or vapour of ether, as the case may be. At the base, where there is a plentiful supply of oxygen, the molecules are burned at once. Higher up the heated products of combustion have time to decompose the combustible vapour before it gets oxygen enough to burn it. In the ether just going out, for want of fresh air, the previous decomposition does not take place, probably because the heat arising from the combustion is divided between a large quantity of inert gas (nitrogen and products of combustion) and the combustible vapour, so that the portion which goes to the latter is not sufficient to decompose it prior to combustion.

In the Bunsen flame fed with chloride of sodium, the absence of scattered light tallies with the testimony of the prism, that the sodium is in the state of vapour, though I would not insist on this proof, as it is possible that the test of scattering sunlight is not sufficiently delicate to show the presence of so small a quantity of matter in a solid or liquid state.—Yours, sincerely,

G. G. STOKES.

P.S.—I fancy the thinness of the stratum of glowing carbon is due to its being attacked on both sides—on the outside by oxygen, on the inside by carbonic acid, which with the glowing carbon would form carbonic oxide.

Note on the Isothermals of Ethyl Oxide. By Prof. Tait.

(Read July 6, 1891.)

The first three pressure-columns of the following little table were constructed from the elaborate data given by Drs Ramsay and Young in their important paper "On Evaporation and Dissociation," Part IV. (*Phil. Mag.*, May 1887). They give, in métres of mercury, the pressures required to confine one gramme of oxide of ethyl to various specified numbers of cubic centimetres, at temperatures near to that of the critical point.

v	193°·8	A	B	C
2	...	...	73·	72·9
2·3	38·6	...	38·55	38·3
2·4	34·	34·3	34·43	34·16
2·5	31·2	31·3	31·53	31·55
2·75	28·	28·1	28·24	28·41
3	...	27·7	27·42	27·45
3·3	...	27·2 +	27·19	27·3
3·7	...	27·2	27·19	27·2
4	...	27·2	27·20	27·2
5	27·	27·1	27·12	27·1
6	26·6	26·7	26·80	26·46
7	25·9	25·9	26·00	25·6
10	22·9	22·9	22·89	22·86
15	18·3	18·4	18·26	18·0
20	15·0	15·0	14·97	14·8
50	7·	7·	7·01	7·02
100	...	3·7	3·69	3·75
300	...	1·27·	1·28	1·32

The values in the second column are taken directly from the paper referred to (Table I.), in which 193°·8 C. is regarded by the Authors as the critical temperature. Those in column A were calculated for temperature 194° C. from the pressures given in the same table for 195° C. and 200° C. (occasionally 210° or 220° C.). Those in column B were calculated, also for 194° C., from Table II. of Drs Ramsay and Young, which contains their "smoothed" values of

the constants. Finally, column C has been computed from my own formula, in forms (given below) which are adapted to volumes greater and less than the critical volume, respectively. A glance at column B shows that, so far as the "smoothed" data are concerned, the critical point should be sought slightly *above* 194° C. For, at that temperature, the pressure has still distinctly a maximum and a minimum value, both corresponding to volumes between 3 and 5. Column A, calculated from the unsmoothed data, does not show this peculiarity. Hence I have assumed, as approximate data for the critical point,

$$\bar{t}=194^\circ \text{ C.}, \quad \bar{p}=27{\cdot}2, \quad \bar{v}=4.$$

The last of these is, I think, probably a little too large; but we have the express statement of Drs Ramsay and Young that the true critical volume is about 4·06.

From their Table II., above referred to, I quote the first two lines below, giving (usually to only 3 significant figures) values of dp/dt at constant volume:—

v	2	2·5	3	4	5	10	20	50	100	300
$\frac{dp}{dt}$	1·60	0·92	·622	·414	·319	·133	·056	·019	·009	·0029
Calc.	...	...	·616	·426	·320	·131	·056	·019	·009	·0029
	1·65	0·90	·633	·405	...	...	...	...	...	...

The third and fourth lines are calculated respectively from the expressions

$$\left(0{\cdot}85+\frac{6}{v+3}\right)\frac{1}{v}, \quad \text{and} \quad \left(1{\cdot}2+\frac{1{\cdot}05}{v-1{\cdot}5}\right)\frac{1}{v};$$

representing the co-ëfficient of $(t-\bar{t})$ in my general formula

$$p=\bar{p}\left(1-\frac{(v-\bar{v})^3}{v(v+\alpha)(v+\gamma)}\right)+\text{R}\left(1+\frac{e}{v+\alpha}\right)\frac{t-\bar{t}}{v}.$$

Approximate values of the other constants are now easily obtained; and we have, for the critical isothermal, while the volume exceeds the critical value,

$$p=27{\cdot}2\left(1-\frac{(v-4)^3}{v(v+3)(v-0{\cdot}5)}\right).$$

In attempting to construct a corresponding formula for volumes

lower than the critical range, I assumed 3·5 as an inferior critical volume, and obtained

$$p=27\cdot2\left(1-\frac{(v-3\cdot5)^3}{v^2(v-1\cdot5)}\right).$$

As will be seen by the numbers in column C above, which are calculated from them, these formulæ represent the experimental results very closely:—but I am not quite satisfied with the first of them, because the value (3), which it assigns to α, seems to be too large in comparison with $\bar{v}$. But, on the other hand, if we much reduce this value of α, the closeness of representation of dp/dt is much impaired. Again, the value $(-1\cdot5)$ which is assigned for α in the second of these formulæ is inconsistent with the fact that at 0° C and 1 atm. the volume of one gramme is 1·4 c.c. nearly. But a very small change of α will entirely remove this objection, and will not perceptibly impair the agreement of the formula with experiment.

The general formula is applicable to temperatures considerably *under* that of the critical point, for volumes greater than 4. In fact Drs Ramsay and Young seem to assert that at *any* constant volume p is a linear function of t. But I think even their own experiments show that, for $v<4$, there is diminution of the value of dp/dt as soon as the temperature falls below the critical value:—*i.e.*, as soon as we begin to deal with liquid alone. And certainly such is the result which theory would lead us to expect.

[It is curious to note that if, in my general formulæ (*Trans. R.S.E.*, xxxvi. p. 265), we assume

$$\alpha=\gamma,$$

we have

$$pv=\mathrm{E}\left(1+\frac{e}{v+\gamma}\right)-\frac{\mathrm{A}-\mathrm{C}}{v+\gamma}+\frac{e\mathrm{C}}{(v+\gamma)^2};$$

and this leads to

$$p=\bar{p}\left(1-\frac{(v-\bar{v})^3}{v(v+\gamma)^2}\right)+\mathrm{R}\left(1+\frac{e}{v+\gamma}\right)\frac{t-\bar{t}}{v};$$

with the condition

$$3\bar{v}+2\gamma=\mathrm{R}\bar{t}/\bar{p}.$$

This formula differs by want of one disposable constant from (C) of the paper referred to, but approximates much more closely to it than does either (A) or (B).]

Additional Observations on the Development and Life-Histories of the Marine Food-Fishes, and the Distribution of their Ova. By Prof. W. C. M'Intosh.

Abstract.

(Read July 20, 1891.)

Since the previous communication to the Society by the author and Professor Prince, not a few dubious points have been cleared up, and, by the courtesy of the Fishery Board for Scotland, further investigations on the general subject carried out at the St Andrews Marine Laboratory. Under the former head may be mentioned the large unknown pelagic egg, with a spacious privitelline space, termed Ovum of Pleuronectid B. This has been proved by Mr E. W. L. Holt to be the egg of the Long Rough Dab, so that the ambiguity which has existed since the Trawling Expeditions of 1884 is now at an end. The larval and early post-larval stages of the species have already been described and figured. A more detailed series of observations have also been made on the development of the Lemon Dab or Lemon "Sole," as it is somewhat ambiguously termed, showing how readily ova can be transmitted long distances, and the larval and post-larval stages reared subsequently. Formerly, only the ovarian egg of Müller's Topknot was described and figured; now the fertilized and free-floating egg and its development have been studied. Like the egg of the Turbot and Brill, this has an oil-globule. The larva is tinted of a deep gamboge-yellow on head, trunk, and upper part of yolk-sac, while the oil-globule is conspicuous at the posterior and lower part of the yolk by an environment of the same bright hue.

Amongst forms hitherto unknown is an ovum somewhat less than that of the Gurnard, with a large privitelline space and an oil-globule. Its development has only been partially followed, and its relationships are unknown. The ova of the three-bearded rockling have been procured in great numbers along with other two species of the same group, and the changes during development described. The most interesting additions, however, are those connected with the larger and the lesser Sand-eels, the reproduction of which was

involved in considerable confusion. Both forms have now been shown to have small demersal eggs which possess a single large coloured oil-globule when ripe, and, moreover, have the *zona radiata* covered by a special papillose layer which causes them to adhere to plates of glass and other foreign bodies. In the larger Sand-eel the oil-globule is greenish yellow, in the lesser it is reddish or brownish yellow. In the earlier stages of the eggs in the ovary, the particles of greenish yellow oil are scattered throughout the granular yolk, but they gradually coalesce until the mature ovarian egg has only a single large globule. Towards the period of hatching, these globules undergo a curious change of tint in the embryos, just before yellowish pigment appears in the trunk, and the special papillose coating of the egg disappears, leaving the zona bare. As in the herring, no vitelline circulation is established, and the yolk is considerably diminished before extrusion. The investigation of the developing eggs has also cleared up the relationships of certain larvæ, such as D and G,* which are shown to be the early stages of the forms under consideration. They occur in great numbers at certain seasons, as in March. It was apparent that they did not spring from pelagic eggs, since these would have been captured by the various nets before the advent of the young forms. It is now evident that two spawning periods or a much prolonged one are characteristic of the Sand-eel, the larvæ of which are found from March to July, or perhaps even later.

By the frequent use of various kinds of tow-nets on board the 'Garland' and at St Andrews, at all seasons, an endeavour has been made to ascertain the distribution of the pelagic eggs of the food-fishes round our shores. They have been found at all depths, surface, midwater, and bottom, and sometimes in great numbers, especially where cod, haddock, whiting, and other forms congregate. Their abundance, as formerly indicated, is generally in keeping with that of the adults in the neighbourhood, though many are swept into adjacent areas where few or no adults occur. Moreover, while there is a general resemblance in the collections of the pelagic ova of the British coasts, certain areas have features of their own. Thus, the floating eggs of the pilchard and mackerel are characteristic of the south and south-west; the eastern waters of Scotland, as off the

* *Trans. Roy. Soc. Edin.*, vol. xxxv. pt. iii. pp. 860, 861, plate viii. fig. 1.

Forth, teem with those of gadoids and pleuronectids, amongst which the cod, haddock, whiting, and long rough dab are conspicuous; while the sea off the west of Scotland, as in the Clyde area, presents such pelagic eggs as those of the variegated sole, witch, mullet-like species and numerous ova of the dragonet. The period of the year is also more or less characterised by the occurrence of certain forms. Thus in January, off the east coast of Scotland, the eggs of rockling and plaice appear, followed by those of the haddock, bib, and long rough dab. In March and April the eggs of the cod, ling, dab, sprat, gurnard, lemon-dab, brill, and other forms are common. As the season advances the ova of the weever, whiting, dragonet, witch, sole, and solenette are found; those of the turbot and topknot appearing towards the end of July.

A Case of Defective Endochondral Ossification in a Human Fœtus (so-called Cretinoid). By Johnson Symington, M.D., and Henry Alexis Thomson, M.D. (With Three Plates.)

(Read June 15, 1891.)

We have ventured to bring our examination of this specimen under the notice of the Society, not so much for its pathological interest, as for the light which it throws upon the normal mode of growth of the skeleton. There has been a tendency of late to regard endochondral ossification as quite secondary in importance to that of membranous ossification, but we believe that the case illustrates in a very striking manner the important part played by ossification in cartilage in the growth of the greater part of the skeleton.

The specimen is a female fœtus, which we received last February from Dr Gonin of Pontypool. It was born at the full time, and the labour was natural, except that the liquor amnii was in great excess, and that the forceps were used to assist the progress of the head.

The father is a healthy man, aged twenty-six years. The mother, who is a year or two younger, suffers from occasional fits, regarded by her doctor as epileptic. They have two healthy children, aged four and two. About three months before this, their third child, was born, the mother was violently assaulted by another woman. There is no history of any relative of the parents having suffered from any malformation of the skeleton.

The fœtus weighed 8 lbs. 2 oz. Its general external appearances are shown in Plate I., which is the reproduction of a photograph taken by ourselves. The most striking feature is the shortness of the upper and lower extremities, which are not only greatly diminished in length, but are very thick, and marked by deep transverse sulci. The head and trunk, on the other hand, are of nearly normal size. A closer examination of the head shows, however, a few peculiarities. Thus its upper part is somewhat enlarged, and the fontanelles are abnormally open. There is a deep sulcus at the root of the nose, which is exaggerated by the forward bulging of the forehead; the nose itself is short and thick. This appearance has been described as resembling that of a bull-dog.

The tongue protrudes from the open mouth 2 cm. beyond the upper lip, and lies upon the projecting lower lip. The trunk, as covered with soft parts, seems well formed. There is a distinct post-anal dimple placed 4 cm. above the anus. The skin, hair, and nails are normal.

Table of Measurements.

Total length from vertex to heel, . . .	40·0 cm.
Length from vertex to perineum, . . .	36·5 cm.
Length from vertex to umbilicus, . . .	28·5 cm.
Length from finger tip to finger tip, with arms abducted at right angles with trunk, .	28 cm.
Total length of arm measured from base of axilla to finger tip, ...	7·6 cm.
Total length of lower limb measured from centre of Poupart's ligament to heel, .	8·7 cm.
Biparietal diameter of head, ...	10·8 cm.
Occipito-frontal diameter of head, . . .	12·3 cm.
Circumference, ...	20·5 cm.

The fœtus was injected as soon as it came into our possession with Müller's fluid, and then kept in this fluid, which was frequently changed.

After the specimen was hardened it was carefully dissected. On reflecting the skin a layer of normal fat was exposed, which was rather thicker than usual. The muscles, blood-vessels, and nerves did not present any unusual variations. The muscles of the extremities had thick short bellies, due to the shortness of the bones. All the viscera were found to present a normal appearance to the naked eye.

The thymus and thyroid were removed, and submitted for examination to Dr G. L. Gulland, who very kindly favoured us with the following report:—

"*Thymus.*—In weight and dimensions decidedly above the normal, but the organ is subject to considerable variations in size. Microscopically there was nothing worth recording, except that the lobules were rather larger than usual, and that the concentric corpuscles were better formed than is usual in a nine months' fœtus.

"*Thyroid.*—Weight and dimensions rather above the normal.

Microscopically the following changes were observed. The acini were irregular in size and shape. The blood-vessels remarkably distended with blood, and here and there so tortuous, as apparently to project into the lumen of the acini. The epithelial cells were of large size, roughly cubical in shape, with a large nucleus and relatively large amount of protoplasm. In some parts the cells were adherent to the walls of the acini, but for the most part were lying loose in their interior, almost filling them with desquamated cells, from some of which, more granular than the rest, the nucleus had disappeared. There was no marked leucocyte infiltration.

"The changes above described may be included in the term acute desquamative catarrh."

As the fœtus had been dead about eight days when we received it, the brain and spinal cord were not sufficiently well preserved for microscopic examination, but we succeeded in demonstrating some interesting changes in the general configuration of the brain. As these, however, were secondary to certain deformities in the cranium, we will defer their description until after that of the skull bones.

The essential and characteristic lesion in this specimen is found in connection with the skeleton; and before proceeding to describe in detail the alterations in the individual bones, it appears advisable to state first, in general terms, that the *alterations present are confined to certain groups of bones, while others are quite normal.* The latter are—

(1) Those which are formed entirely in membrane, *e.g.*, the flat bones of the vault of the skull.

(2) Those which, although formed in cartilage, remain entirely or mainly cartilaginous till an advanced period of fœtal life, so that their general growth is quite independent of endochondral ossification. As examples of these may be mentioned the sternum, costal cartilages, patella, and the tarsal and carpal bones.

The departures from the normal affect those parts of the skeleton which, formed in cartilage, largely depend for their growth during fœtal life upon endochondral ossification, the cause of the departure being a premature arrest or absence of this process. The bones belonging to this group are the long bones of the extremities, the ribs, the posterior part of the base of the skull and the innominate bones.

SKULL.—As the growth and ossification of the skull is a very complex process it affords numerous illustrations of the above generalisations. Thus the various membrane bones are normal, the parts cartilaginous at birth are of their usual size and form, while those bones which are ossified from cartilage at an early period of fœtal life are considerably modified. Further, we find at the base of the skull a marked synostosis of certain bony centres. After the entire head with the brain *in situ* had been well hardened in Müller's fluid, a sagittal mesial section was made with a large knife. Similar preparations were made of the head of a normal nine months' fœtus for purposes of comparison. In the sections thus obtained, the principal alterations in the base of the skull are well seen. (See Plate II. figs. 1 and 2.)

The part of the base which extends from the foramen magnum to the anterior edge of the pre-sphenoid is abnormally short, measuring 2·4 cm. only, as compared with 3·6 cm. in the normal fœtus. This shortened portion of the base is represented by a single osseous nucleus, the os tribasilare of Virchow, so called because it corresponds to the three nuclei—basi-occipital, post-sphenoid, and pre-sphenoid, which Virchow found united in the skull of a cretin.

This single osseous nucleus consists of cancellous bone, its margins are regular, excepting the anterior which is markedly irregular, presenting a number of tapering processes which project forwards into the cartilage. This nucleus is usually regarded as being formed by the fusion of three originally distinct nuclei by a process of synostosis; the appearance of the anterior margin, as above described, suggests the probability that, at any-rate, the pre-sphenoid element has been formed by an extension from an osseous centre lying posterior to it, and not from a separate centre.

The mesial portion of the base of the skull in front of the sphenoid being normally cartilaginous at birth, is in this specimen of normal length. Thus the distance from the anterior edge of the os tribasilare to the level of the fronto-nasal suture was 3 cm., and in the normal fœtus the distance was the same from the anterior edge of the pre-sphenoid nucleus to the fronto-nasal suture. The continuation of the mes-ethmoid cartilage under the nasal

bones towards the tip of the nose is also normal. We find, therefore, a distinct shortening of the base of the cranium in front of the foramen magnum, this shortening being limited to the parts normally ossified at birth, by intra-cartilaginous ossification.

Occipital bone.—The upper portion of the supra-occipital (inter-parietal bone of comparative anatomists) which is developed in membrane is well formed; its junction with the lower portion of the supra-occipital is indicated by the usual fissure extending inwards from the margin on either side. All the parts of the occipital bone ossified from cartilage, viz., the lower part of the supra-occipital, the ex-occipitals, and the basi-occipital, are much smaller than normal, and are not separated from one another by cartilage as in the normal fœtus; the lower part of the supra-occipital being ossified to the ex-occipitals, whereas normally they are separated by a layer of cartilage several millimetres in thickness. Again, the cartilage between the ex-occipitals and the basi-occipital is absent, although there is no osseous union of these bones. The changes in the basi-occipital have already been described. The foramen magnum is remarkably diminished in size, measuring only ·65 cm. in its antero-posterior diameter, compared with 2·2 cm., which we found to be the average of four normal skulls. This diminution is, of course, the direct result of the premature ossification and arrested development of the four elements of the occipital bone which surround the foramen, and by the growth of which the foramen increases in size.

Sphenoid.—As already mentioned, the pre- and post-sphenoidal nuclei, together with the basi-occipital, are represented by a single osseous mass, the os tribasilare. The pituitary fossa is distinctly smaller than usual, its antero-posterior diameter being ·6 cm. as compared with 1·0 cm. The orbito-sphenoids, or lesser wings, are smaller. The alæ-sphenoids (greater wings), on the other hand, are fully as large as normal; this suggests that they are not formed entirely in cartilage as commonly described, but partly in membrane, and the radiating appearance of their outer edge supports this view.

Ethmoid.—The mes-ethmoid, which is normally cartilaginous at birth, is, as we have already mentioned, of normal size. Its lateral masses, although well ossified, are distinctly smaller than

normal. The inferior turbinate, a cartilage bone, is also small and well ossified.

Temporal bone.—The membranous portions (squamo-zygomatic and tympanic) are normal, but the petro-mastoid, developed in cartilage, is distinctly smaller than normal, and its cranial surface is irregular in form, the prominence of the superior semicircular canal and the floccular fossa being indistinct. The auditory ossicles are well ossified, and are practically normal in size.

All the foramina piercing the cartilaginous portion of the base of the skull are distinctly diminished in size. The bones forming the vault of the skull—frontals, parietals, and upper part of supra-occipital are normally ossified, but the calvaria presents certain peculiarities. Thus all the fontanelles, mesial and lateral, are enlarged, and the two halves of the frontal and the two parietals are further apart than normal. The reason of the enlargement of the fontanelles is found in the fact that the base of the skull is so short that an abnormal separation of the bones of the vault was necessary to give space for the growing brain. For the same reason the vertical plates of the frontal are bulged forwards. There is, therefore, a general enlargement of the vault of the skull compensatory in character. All the facial bones developed in membrane are practically normal.

The lower jaw is the only one presenting any peculiarity. The ossification of this bone is complex, it being formed partly in cartilage and partly in membrane. On the whole it is distinctly smaller than normal; thus it measured 3·3 cm. along the lower body of the body from the angle to the symphysis, as compared with 4·5 in a normal specimen. The vertical depth of the body was very slightly diminished.

The portion of the body in front of the mental foramen was of normal length, but its anterior extremity corresponding to the central incisor was partly cartilaginous and imperfectly united with the rest of the bone. This is the only portion of the lower jaw which is formed by the ossification of Meckel's cartilage, the greater part of the body of the jaw being ossified in membrane external to Meckel's cartilage. The small size of the lower jaw was evidently due to the fact that its posterior portion is ossified in cartilage.

Before proceeding to the examination of the other parts of the

skeleton, a brief reference may be made to the condition of the Brain. This organ was hardened *in situ*, and the entire head was then divided by a sagittal mesial section. Fig. 2 of Plate II. is a drawing of the right half of part of this section, while fig. 1 on the same plate shows the same structures in a normal nine months' fœtus. A comparison of these two figures will demonstrate the fact that the normal relations of the brain have been considerably altered, these alterations being secondary to those in the skull.

The lower part of the medulla is notably diminished in size; this is probably due to the smallness of the foramen magnum. The medulla and pons normally extend from the foramen magnum to the upper edge of the dorsum sellæ, but in this case fully one-half of the pons lies above the level of the dorsum sellæ. The long axis of the medulla and pons, which is usually directed from below upwards and somewhat forwards, is here inclined upwards and backwards.

These changes were obviously due to the decrease in the length of the base of the skull in front of the foramen magnum. The optic thalami are also displaced backwards and upwards, and lie between the splenium of the corpus callosum above and the corpora quadrigemina below. Normally these two structures are only about ·3 cm. apart, while in our case they are separated a distance of 1·3 cm. as measured from the splenium to the upper extremity of the nates. The posterior part of the corpus callosum is pushed upwards so that its antero-posterior arch is less marked than usual. The most striking changes, however, we found in connection with the form and position of the cerebellum, which is flattened from above downwards and backwards, so that its long axis is directed from the foramen magnum upwards and backwards. Associated with this, there is an alteration in the attachment of the tentorium and in the situation of the lateral sinus, while the falx cerebelli is greatly increased in length. The torcular Herophili is 6·3 cm. distant from the posterior edge of the foramen magnum, whereas it is generally about 2·5 cm. The lateral sinus and attachment of the tentorium cerebelli correspond to the lambdoidal suture, so that the cerebellar fossa reaches to the upper limit of the supra-occipital. No distension of the third or fourth ventricles, the aqueduct of Sylvius or the foramen of Monro, is seen in the mesial section; and after the removal of one-half of the brain and cutting into it, the lateral ventricle was also found of the

normal size. In the description of several specimens of a similar nature to ours, hydrocephalus has been assumed to exist from the appearance of the vault of the dried skull in which the fontanelles were increased in size. As already pointed out, we believe this condition of the vault is due to the marked diminution in the dimensions of the base of the skull, causing the brain to be displaced upwards, and in this way leading to the expansion of the vault.

The pituitary body was examined microscopically and found normal.

VERTEBRAL COLUMN.—The spine does not differ in length from that of a normal fœtus (24 cm.); it presents an abnormal curve forwards in its thoracic segment and an unusual degree of lordosis in the lumbo-sacral region; both were found to depend on alterations in the thorax and pelvis respectively, as will be described.

A mesial sagittal section of the spine showed (1) that the ossifying nucleus in the centre of each body was only one-half of the normal size, and (2) that the antero-posterior diameter of each body was ·3 cm. less than the average, while the vertical diameter as already mentioned is quite normal. This is explained by the fact that the vertebral bodies grow in the antero-posterior diameter during fœtal life by progressive ossification, while increase in their vertical diameter is dependent upon cartilaginous growth. There was no deficiency in the number of the osseous nuclei throughout the spine. The amount of central soft substance in the intervertebral discs was excessive.

The fourth to the seventh dorsal vertebræ inclusive were examined microscopically; the appearances which they present will be discussed with those found in the other bones.

THORAX.—The thorax, after removal of the soft parts, was found remarkably small and flattened, and on either side presented a furrow or depression along the line of junction of the ribs with their cartilages.

The diminution in the capacity of the thorax is indicated by the following comparative measurements—

Greatest antero-posterior diameter, 3·6 cm. in the specimen, 5·3 in the normal fœtus.

Greatest transverse diameter, 4·4 cm. in the specimen, 8 in the normal fœtus.

This remarkable contraction of the chest was found to depend entirely upon the arrested development of the ribs; the latter are less than half the normal length at birth, while the costal cartilages are of the full average size.

The longest, or 7th rib, measured along the convexity 3·2 cm. in the specimen, 7·8 in the normal.

The longest, or 7th costal cartilage, measured along the convexity 5·4 cm. in the specimen, 6 in the normal.

The ribs are sharply curved, and join their cartilages at an angle. Externally this angular junction is responsible for the furrow mentioned above, while on the internal or pleural aspect it forms a prominent projection, like that of a rosary.

Further, as a result of their shortness, the ribs are more horizontal than normal, and the costal extremity of each is slightly cupped.

The 7th rib and its cartilage were examined microscopically; the appearances observed will be afterwards referred to.

The sternum is of full size and is well formed; it consists entirely of normal hyaline cartilage, without any trace of osseous nuclei.

The PELVIS, like the thorax, is remarkably contracted in all its diameters, especially, however, in the conjugate at the brim, which is less than half of the same diameter at birth.

Conjugate at the brim in the specimen,	1·3,	in the normal	2·8 cm.
Transverse, „ „ „	2·8	„ „	3·6 „
Interspinous diameter, . . .	5·6	„ „	7·4 „

The pelvis is, therefore, generally contracted and flat. Further, the diminution in the size of the pelvis is shown by the fact that the tip of the coccyx projects 3·1 cm. below the level of the lower border of the pubic symphysis, and 2 cm. below the level of the ischial tuberosity.

The above alterations are entirely due to the early arrest of the osseous growth of the constituent elements of the ossa innominata, while the sacro-coccygeal portion of the spine is of the usual size and length, being so independently of ossification. The innominate bone, as examined after dehydration and clearing in naphtha, was found to consist almost entirely of cartilage, the normal osseous

nuclei, to the number of three, having remained exceedingly small. In consequence of this arrest of ossification, the entire bone is dwarfed and sharply curved upon itself, causing the flattening and contraction of the pelvis already referred to. The acetabular cavity was of normal size.

Dimensions of innominate bone :—

Total height from crest to tuber ischii, in the specimen 4·8, in the normal 6·5 cm.

Breadth of ilium from anterior to posterior spine, in the specimen 3·3, in the normal 4·4 cm.

Bones of the Extremities.—The various long bones, inasmuch as they depend for their growth in length upon a progressive cartilaginous ossification during fœtal as well as during extra-uterine life, have especially suffered from the arrest of this process. Their total length is, in general terms, only one-half of the normal, as can be readily seen from the following comparative measurements :—

	In specimen.	In normal fœtus.		In specimen.	In normal fœtus.
Humerus, ...	3·6	8·4 cm.	Femur, ...	4	10 cm.
Radius, ...	2·7	6·4 ,,	Tibia, ...	3·8	8 ,,
Ulna, ...	2·8	7·3 ,,	Fibula, ...	3·3	7·8 ,,
Metacarpals, . . .	1·2	1·8 ,,	Metatarsals, . . .	·8	2·3 ,,
Proximal phalanges,	·8	1·2 ,,	Proximal phalanges,	·5	1 ,,

These measurements do not fully represent the degree of defective endochondral ossification, because the cartilaginous ends of the bones are of normal size, and the shortening is confined to the diaphyses. This is readily explained by the fact that the cartilaginous ends during fœtal life increase in size by growth of cartilage, while, in the case of the shafts, the increase is the result of progressive ossification.

The diaphysis is seen, from the following measurements, to be only about one-third of the normal length :—

Length of diaphysis of humerus, in specimen 2·1, in normal 6 cm.
,, ,, femur, ,, 2·2, ,, 7 ,,
,, ,, fibula, ,, 1·6, ,, 5·8 ,,

In circumference the shafts are quite normal. With scarcely an exception the shafts present very pronounced curvatures, which are in each case an exaggeration of the normal curve of the bone. The humerus is abruptly curved forwards in its lower half, the radius and ulna are uniformly curved, with the concavity on the flexor aspect. The femur is bent almost to a right angle at the junction of the shaft with the lower end, the angle being open posteriorly. The tibia is uniformly convex forwards, and the fibula backwards. The metacarpals and metatarsals have practically no shaft; they possess a minute central osseous nucleus, which is almost surrounded by the cartilaginous ends.

The curvatures we have described do not appear to result, like those met with in rickets, from softness of the bones. The shafts are firm and rigid. We would suggest that they depend upon arrest of the cartilaginous ossification and consequent arrest of growth in the axial portion of the shaft, while the peripheral membranous ossification continues.

Lastly, the secondary centres of ossification or epiphyses at the ends of long bones, which are normally present at birth, *e.g.*, in lower end of femur and upper end of tibia, are entirely absent.

The joints of the extremities have suffered in function in consequence of the alterations in the bones. They are disproportionate in size, and their movements are seriously restricted by the large size of the cartilaginous ends of the bones over which the ligaments are tightly stretched. Generally speaking, all the joints are fixed in the flexed position.

The condition of the short bones of the extremities is similar to that of the short bones of the trunk. Those which are cartilaginous at birth are of normal size, *e.g.*, carpus. Those which have a central osseous nucleus at birth, *e.g.*, astragalus, os calcis, but which do not depend for their growth on ossification proceeding from the nucleus, are also of normal size. The central nucleus, however, is distinctly smaller.

The difference between the long and short bones is well illustrated by a longitudinal section of the foot passing through the great toe, the tarsus being found of normal size, while the metatarsals and phalanges are extremely short.

SCAPULA AND CLAVICLE.—Both these bones were slightly below the normal size—

	Spec.	Normal.
Clavicle—total length, . .	3·7	4·5
Scapula—height, . . .	4·2	4·4
„ greatest breadth, . .	2·3	2·6

Microscopical appearances observed in the different Bones of the Skeleton.—After hardening in Müller's fluid, the bones were decalcified in "Perenje" and embedded in paraffin. Complete sections were then cut with the large microtome, and mounted in approximate series.

Before entering into details, we may state at once that we found no evidence whatsoever of any disease known to affect the fœtal skeleton, *e.g.*, syphilis, rickets. The essential lesion showed itself as an absence, arrest, or perversion of the normal process of endochondral ossification of the most definite and universal character in every element of the skeleton in which the process normally takes place during intrauterine life. All the peculiarities which we have described in the specimen are referable to the perversion of ossification, and to this alone.

In the examination of the long bones we found that complete sections were of great assistance, especially on comparing these with similar preparations of the normal nine months' fœtus.

The large cartilaginous ends consisted of normal hyaline cartilage, actively growing, covered by perichondrium, and traversed by numerous large blood-vessels (see Plate III.). The short curved shafts consisted almost exclusively of periosteal bone; the periosteum itself being actively engaged in ossification in the usual way; the surface layer beneath the membrane is less compact than is usually the case. From the surface layer a regular system of trabeculæ stretches right across the entire thickness of the shaft, to meet a similar series on the opposite side. Peripherally these trabeculæ are closely approximated, and are for the most part parallel to each other. In the centre the spaces between the trabeculæ are larger and more open, and are filled with marrow; there is, however, an entire absence of anything in the shape of a medullary canal or endosteum. The process of excavation or hollowing out of the central core of the shaft, so evident in normal bones, is nowhere

present. The entire thickness is occupied by the periosteal bone, as described. This condition of affairs naturally presents an important obstacle to the development and ramification of the medullary blood-vessels; their extension or projection towards the ossifying junction at the ends of the diaphysis would be specially interfered with. Probably this interference with the vessels has played an important part in the causation of the arrest in endochondral ossification, to be immediately described.

The marrow itself is rich in small vessels, chiefly capillaries, while it is deficient in those of larger size. Further, very few giant cells are to be seen, and scarcely any Howships' foveolæ. The periosteal bone is almost continuously invested by osteoblasts. At the ends of the shaft the periosteal diaphysis is peripherally extended so as to form a cup, which embraces the cartilaginous extremity and a small wedge-shaped mass of endochondral bone. The apex and sides of this endochondral wedge occupy the concavity of the cup, while its base corresponds to the junction between it and the terminal cartilage (see Plate III.).

Although the endochondral and periosteal bone are thus in immediate contact, they are readily differentiated from each other by their structure and connections. The ossifying junction between the endochondral bone and the terminal cartilage is in the form of an irregularly curved line, concave towards the diaphysis. The endochondral bone consists of a very irregular honeycomb, made up of branching masses, each of which contains a core of cartilage in the centre; the bone is non-lamellated, and stains very intensely with carmine or eosine. It appears to have been formed by a direct conversion or metaplasia of the cartilage into bone, after the manner described by Kassowitz,* as occurring in the course of normal ossification in cartilage, and similar to the process observed under pathological conditions in cartilage of new formation. By direct conversion of cartilage into bone, we further mean to convey that there is an entire absence of proliferative changes, or of any activity whatsoever in the cartilage itself, previous to its ossification; there are no parallel rows of cells, no progressive formation of medullary spaces by the projection of medullary blood-vessels into the carti-

* *Die Normale Ossification*, Wien, 1881.

lage. There is an absence of vessels at the ossifying junction. The typical organ-pipe arrangement of structures at the ossifying junction is either not recognisable at all, or only here and there, and that faintly. In several of the bones we further noticed that the zone of cartilage immediately adjoining the ossifying junction was sharply defined or cut off from the main mass of cartilage above it by a curved line or layer, in which the cartilage matrix is partially fibrillated, and the cells flattened and crowded together, resembling the tissue arrangement seen in perichondrium.

The appearances described sufficiently account for the remarkable external appearances of the long bones.

Previous observers who have examined specimens similar to that under consideration, describe as characteristic, the occurrence of an intrusion from the periosteum between the diaphysis and epiphysis, which interferes with the development of bone from the latter (Eberth, Urtel, Bode). We believe this appearance to be fallacious; it is merely the result of the disproportion in size between the shaft and the terminal cartilage, together with the abrupt curvature of the shaft close to their junction. The apparent intrusion is only seen at the concavity of the curve, in sections close to the surface of the bone. In making our serial sections of the entire bone in its long axis from the surface inwards, we observed that no such intrusion was visible when the level was reached at which complete sections were obtained.

The other bones were examined on similar lines; the seventh rib, for example, with its cartilage, presented appearances which might be exactly compared to those seen in one-half of a long bone; the short diaphysis of the rib consisted entirely of periosteal bone, cup-shaped at the costal end so as to embrace the cartilage,—a similar arrest of endochondral ossification being observed at the ossifying junction.

In the bodies of the vertebræ, the os calcis and astragalus, there was a complete arrest of the ossifying process at the junction of the small central nucleus with the surrounding cartilage; the bone already formed being for the most part metaplastic, while the marrow was deficient in large vessels and in giant cells. It is obvious that the arrest of ossification in these bones is not to be ascribed to a continuous and excessive formation of periosteal bone

without its simultaneous removal or absorption in the interior, which we described as the prominent feature in the long bones. Nor can we ascribe the arrest to deficient vascularisation of the general cartilaginous mass in which the arrested nucleus is embedded, for the number and size of the vascular canals in the cartilage is quite equal to the normal. We are absolutely unable to account for the arrested growth in the osseous nuclei in the vertebral bodies, in the os calcis and astragalus, &c., and also for the complete absence of ossifying centres in these bones in which these are normally present at birth (*e.g.*, sternum).

Eberth and Müller are of opinion that the arrested development of endochondral bone is the result of an interference arising from an enormous overgrowth of the periosteal bone, while Klebs holds the view that the origin lies in an imperfect development of the medullary vessels supplied to cartilage. We cannot accept the former, because it will not hold for the arrest observed in parts of the skeleton, *e.g.*, os calcis, where there is no periosteal growth whatever, far less excessive growth; while as regards the latter, our examination of the bones does not show any imperfection in the vessels supplied to cartilage in bones devoid of an external periosteal crust (os calcis). The arteries and nerves of the extremities presented no alteration in their microscopical structure.

Most of the published descriptions of similar specimens indicate that the authors are of opinion that it is a real disease of the fœtus, instead of regarding the condition, as we do, as a simple arrest of a normal process. Hence many observers describe it as a fœtal form of sporadic cretinism, others as a form of fœtal rickets. From the latter it is readily differentiated.

Its resemblances to rickets are only apparent, thus:—

1. The open fontanelles do not indicate hydrocephalus as has been assumed, but are simply due to the enlargement of the vertex compensatory to the contraction of the base.
2. The contracted chest, the external furrow at the costichondral junctions, the apparent rosary, are not due to rachitic changes, but to the shortness of the ribs from arrest of ossification; the short ribs joining the long cartilages at an angle.

3. The contracted and flat pelvis is not due to softness of the bones, but simply and solely to arrested growth of the innominate bones.
4. The large size of the ends of the long bones is only apparent; their measurements are the same as the ends of normal bones.
5. The curvatures of the long bones are not the result of any softening, but due to arrest of the central cartilaginous growth and progressive periosteal growth from the periphery inwards. The curves, moreover, are all exaggerations of the normal curves.
6. The histological changes at the ossifying junctions of the long bones are strikingly different from those seen in rickets.
7. The membrane bones which participate in rachitic processes are quite normal.
8. There is not such a thing as a microscopical record of a progressing fœtal rickets, hence its occurrence only rests upon conjecture.

The question whether it is, or is not, a fœtal form of cretinism is less easily disposed of, chiefly because we really know so very little about cretinism. In the published description of what is called sporadic cretinism, the most striking lesion appears to be a premature arrest of endochondral ossification occurring during infancy or childhood, like that we have here described as having taken place during the early months of intra-uterine life. Further, certain abnormalities of the thyroid have been met with in the former; and in our specimen there are distinctly abnormal changes in the same organ, consisting in proliferation and desquamation of the alveolar epithelium, together with an extraordinary fulness and distension of the blood-vessels.

With reference to the causation of the lesion, we do not regard the assault received by the mother during the sixth month of her pregnancy as of any etiological importance, in virtue of the evident fact that the arrest of development occurred at a much earlier period.

A. RITCHIE & SON, EDINR.

Proc. Roy. Soc. Edin. Vol XVIII

Plate 1.

Plate 3.

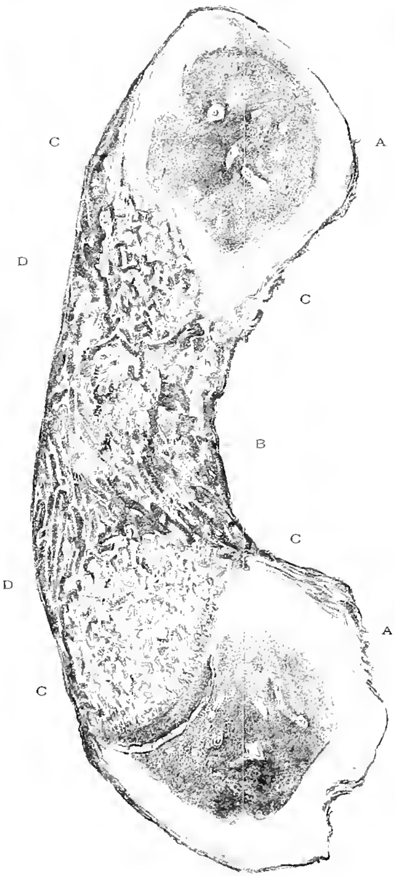
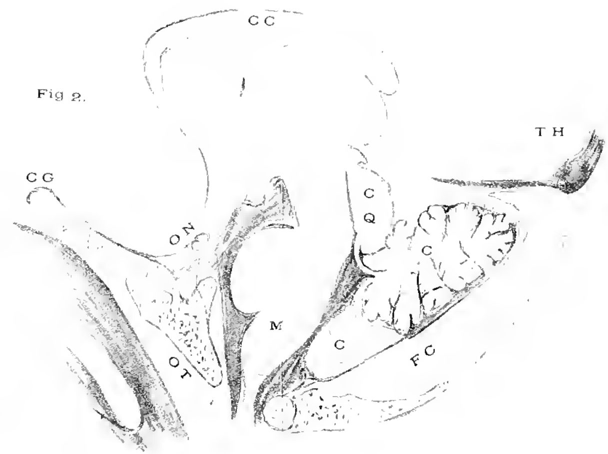


Plate 2.

Fig 1

Fig 2.



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EXPLANATION OF PLATES.

Plate I.

Reproduction from a photograph of the fœtus as seen from behind.

Plate II.

Fig. 1. *v.m.* section of base of skull and adjacent brain of a normal nine months' fœtus—natural size; *B.O.*, basi-occipital; *B.S.*, basi-sphenoid; *p.s.*, pre-sphenoid; *s.o.*, supra-occipital; *c.g.*, crista galli; *m.*, medulla oblongata; *p.* pons varolli; *c.q.*, corpora quadrigemina; *c.c.*, corpus callosum; *O.N.*, optic nerve; *c.*, mesial lobe of cerebellum; *c'.*, lateral lobe of cerebellum; *F.C.*, falx cerebelli; *T.H.*, torcular Herophili.

Fig. 2. *v.m.* section of corresponding region of specimen; *O.T.*, os tribasilare, representing the three nuclei, *B.O.*, *B.S.*, and *P.S.*, seen in fig. 1. Other lettering as in fig. 1.

Plate III.

Longitudinal section of right fibula × 6. *A.A.*, cartilaginous extremities traversed by vascular canals; *B.*, periosteal bone constituting the greater part of the diaphysis; *C.C.C.C.*, peripheral prolongation of periosteal bone embracing cartilaginous extremity; *D.D.*, wedge-shaped masses of endochondral bone.

On the Blood of the Invertebrata. By Dr A. B. Griffiths, F.R.S.E., F.C.S., &c.

(Read 1st June 1891.)

I. *The Gases of the Blood.*—As very little is known concerning the composition and nature of the gases in the blood of the *Invertebrata*, the following notes may be of some value.

The author has ascertained the approximate composition of the gases in the blood of certain Invertebrate animals. The apparatus used for this purpose was that of Gautier slightly modified (fig. 1); and the method allows the collection of the blood *in vacuo* (from the time of leaving the vein, &c.) without any alteration in its composition. The glass receiver ACD (left-hand figure), in which the vacuum is made, has a canula E fastened to its lower end. The canula is drawn out into a fine capillary point, which is pushed into the artery, vein, or under the hypodermis, as the case may be. After introducing the canula into the blood system, the tap B is opened and the blood rises into the receiver. The gases are evolved almost immediately, and by means of the pump they are collected over mercury in the tube *ab*, where their composition is ascertained.

After the introduction of the blood into the receiver the tap B is turned off; the receiver is then attached to the pump. Before opening the tap A, the receiver is placed in a bath of water heated to about 40° C. The heat assists in the liberation of the gases from the blood. Coagulation is prevented by previously introducing a small quantity of sodium chloride into the receiver (*i.e.*, before the introduction of the blood).*

The pump and pneumatic trough do not require description, as they are of the usual kind. The volume of the mixed gases collected in *ab* having been ascertained, the percentage of each gas is estimated by the ordinary methods of gas analysis. The carbonic

* The liberation of carbonic anhydride is accelerated by previously introducing into the receiver a small quantity of a hot solution of tartaric acid.

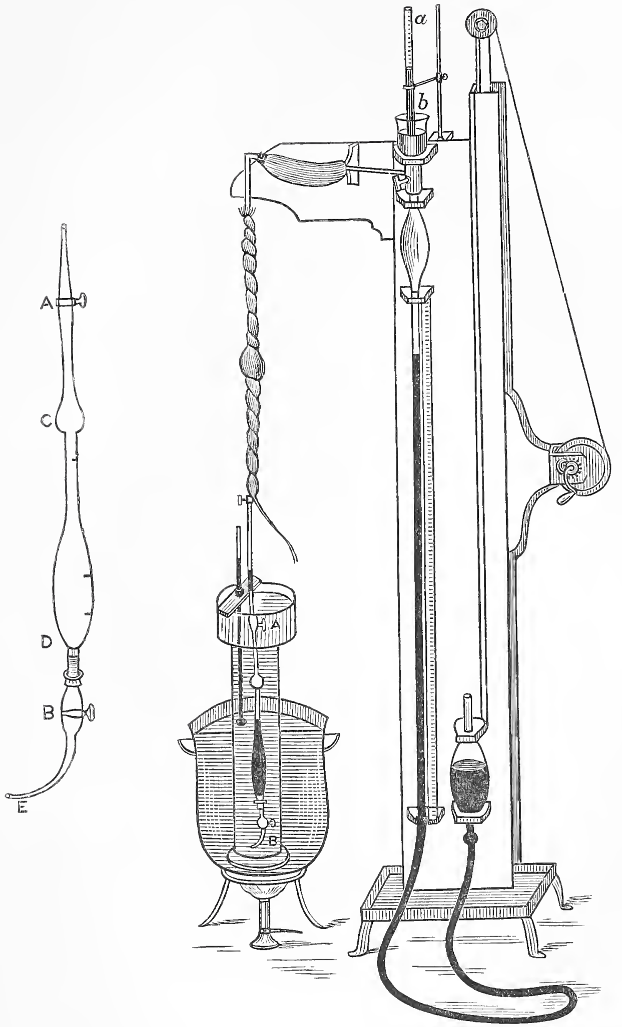


Fig. 1.

Apparatus for Extracting, &c., the Gases of the Blood.

anhydride is absorbed by potash, the oxygen by pyrogallic acid, whilst the amount of nitrogen is represented by what remains.

(*a*) *Blood of Sepia officinalis.*

100 volumes of the blood of the cuttle-fish contained the following volumes of the three gases—the volumes being reduced to 0° C. and 760 mm. :—

	I.	II.	III.	IV.	V.	VI.
Oxygen, . .	13·26	12·91	13·14	14·62	14·21	14·34
Carbonic anhydride,	30·12	31·21	32·10	30·14	29·12	29·89
Nitrogen, . .	1·60	2·00	1·51	1·41	1·73	1·23

The nitrogen is simply dissolved in the blood, but the oxygen and carbonic anhydride are partly dissolved, and partly in a state of loose chemical combination with certain constituents of the blood. The oxygen with the hæmocyanin; and possibly the greater part of the carbonic anhydride is united to certain salts contained in the blood.

(*b*) *Blood of Cancer pagurus.*

The blood was obtained from very large individuals, by opening the carapace and passing the capillary point of the canula directly into the heart.

100 volumes of the blood yielded the following volumes of oxygen, carbonic anhydride, and nitrogen, after being reduced to 0° C. and 760 mm. :—

	I.	II.	III.	IV.
Oxygen, ...	14·79	14·88	14·96	14·85
Carbonic anhydride, . . .	28·62	27·21	27·14	28·39
Nitrogen, ...	1·01	1·20	1·22	1·30

(c) Blood of Palinurus vulgaris.

100 volumes of the blood of this animal gave the following results :—

	I.	II.	III.	IV.
Oxygen, ...	14·62	14·71	14·29	14·76
Carbonic anhydride, . . .	30·00	29·62	28·92	29·79
Nitrogen, ...	1·82	1·60	1·20	1·34

(d) Blood of Homarus vulgaris.

100 volumes of the blood obtained from several large lobsters yielded the following results :—

	I.	II.	III.
Oxygen, ...	14·99	14·81	14·85
Carbonic anhydride, ...	31·11	28·84	29·26
Nitrogen, ...	1·76	1·82	1·85

(e) Blood of Octopus vulgaris.

100 volumes of the blood yielded the following results :—

	I.	II.	III.
Oxygen, ...	13·33	13·28	13·65
Carbonic anhydride, ...	30·23	31·29	31·22
Nitrogen, ...	1·45	1·30	1·29

(f) Blood of Acherontia atropos.

100 volumes of the blood of the larvæ of this moth yielded the following results :—

	I.	II.
Oxygen,	16·21	16·79
Carbonic anhydride,	32·92	34·24
Nitrogen,	1·09	1·98

It may be stated that the oxygen and carbonic anhydride in the blood of the *Invertebrata* do not behave according to the law of Dalton (the law of partial pressures) in regard to the absorption of a mixture of gases by a simple fluid. A portion of each gas combines chemically with some constituent or constituents of the blood. It was Magnus (*Poggendorff's Annalen*, vol. xl. p. 583) who first demonstrated that the carbonic anhydride and oxygen of the Vertebrate blood did not obey the law of Dalton; and the same is true concerning the gases of the blood of the *Invertebrata*.

II. *The Mineral Matter in the Blood.*—The percentages of saline matter contained in the blood of various Invertebrates is given in the following table:—

		I.	II.	III.	Average.
Pulmo-gastero-poda.	*Helix pomatia*,	1·065	1·072	1·069	1·068
	Helix aspersa,	1·079	1·080	1·062	1·077
	Limnæus stagnalis,	1·200	1·203	1·210	1·204
	Limax flavus,	1·122	1·100	1·115	1·112
	Limax maximus,	1·119	1·127	1·114	1·120
Branchio-gastero-poda.	*Buccinum undatum*,	1·699	1·710	1·698	1·702
	Patella vulgata,	1·706	1·721	1·719	1·715
	Anodonta cygnea,	1·002	0·998	1·006	1·002
	Mytilus edulis,	1·796	1·799	1·810	1·801
Cepha-lopoda.	*Sepia officinalis*,	2·840	2·862	2·851	2·851
	Octopus vulgaris,	3·004	3·032	3·020	3·018

The author has also submitted to analysis the ashes of the blood of several Invertebrate animals. The ashes were obtained by incinerating the blood, partially covered, in a platinum dish at a very low temperature. By so doing the alkaline metals are not volatilised as they are when a high temperature is used. The following results represent the averages of three analyses in each case:—

	Cancer pagurus.	*Carcinus mœnas.*	*Astacus fluviatilis.*	*Palinurus vulgaris.*	*Homarus vulgaris.*
Copper oxide (CuO), .	0·22	0·19	0·20	0·18	0·18
Iron oxide (Fe_2O_3), .	trace.	trace.	...	...	trace.
Lime (CaO), . .	3·55	3·57	3·58	3·79	3·54
Magnesia (MgO), .	1·91	1·89	1·88	1·90	1·89
Potash (K_2O), . .	4·97	4·78	4·82	4·92	4·77
Soda (Na_2O), . .	43·90	44·91	44·96	43·98	44·99
Phosphoric acid (P_2O_5),	4·90	4·86	4·81	4·87	4·84
Sulphuric acid (SO_3), .	2·90	2·81	2·75	2·86	2·81
Chlorine, . . .	37·65	36·98	37·00	37·50	36·96
	100·00	99·99	100·00	100·00	99·98

	Anodonta cygnea.	*Mytilus edulis.*	*Pinna squamosa.*	*Sepia officinalis.*	*Octopus vulgaris.*
Copper oxide (CuO), .	0·23	0·22	trace.	0·24	0·21
Manganese oxide (MnO_2), . .	...	trace.	0·19	...	...
Iron oxide (Fe_2O_3), .	...	...	trace.	...	...
Lime (CaO), . .	3·61	3·72	3·70	2·31	2·40
Magnesia (MgO), .	1·82	1·86	1·83	1·51	1·55
Potash (K_2O), . .	4·90	4·80	4·86	4·92	4·90
Soda (Na_2O), . .	44·18	43·90	44·02	45·40	45·31
Phosphoric acid (P_2O_5),	4·89	4·82	4·79	4·90	4·88
Sulphuric acid (SO_3), .	2·80	2·76	2·73	2·81	2·83
Lithium,* . . .	trace.	...	...	...	...
Chlorine, . . .	37·55	37·92	37·88	37·90	37·92
	99·98	100·00	100·00	99·99	100·00

There is no doubt, from the above analyses, that copper † plays an important part in the blood of the *Invertebrata;* in fact it plays a similar *rôle* to iron in the blood of the higher *Vertebrata.* ‡

In the majority of the *Invertebrata* the carrier of oxygen to the tissues is hæmocyanin § contained in the blood; but in many of the *Annelida,* as well as in nearly all Vertebrates, the transport of oxygen from the surrounding medium (air or water) to the living tissues is made by means of the hæmoglobin of the blood.

* Detected by the spectroscope.

† See Dr Griffiths' paper in *Chemical News,* vol. 48, p. 37; also *Journal Chemical Society,* 1884, p. 94.

‡ In *Pinna squamosa,* the copper is replaced by manganese.

§ Fredericq in *Archives de Zoologie Expérimentale,* 1878; see also his book *La Lutte pour l'Existence,* p. 84.

This substance (as is well known) forms an oxygenised combination which is very unstable, and which is carried by the blood across the tissues of the animal, and is there dissociated, yielding its oxygen to the elements of those tissues which require it.

Professor Ray Lankester discovered that in some of the *Annelida* the hæmoglobin is replaced by a green-colouring matter—chlorocruorin; but in the majority of these animals hæmoglobin is present, which the author has proved to be similar in composition to that present in the higher animals. Concerning this point, the author obtained the blood of 500 earthworms (*Lumbricus terrestris*) which was treated with benzene. The mixture (in solution) was allowed to stand for twenty-four hours at 0° C., when it separated into two distinct layers. The one containing the colouring matter was now separated from the other; and about one-sixth its volume of pure absolute alcohol was added. After filtration the alcoholic extract was exposed to −12° C., when red crystals were obtained. These crystals yielded the following results on analysis:—

	Blood of *Lumbricus*.			Blood of Dog.
	I.	II.	III.	
Carbon,	53·91	53·86	...	52·85
Hydrogen,	7·02	7·10	...	7·32
Nitrogen,	...	...	...	16·17
Sulphur,	0·41	0·37	...	0·39
Iron,	...	...	0·39	0·43
Oxygen,	...	...	...	21·84

The above analyses prove that the colouring matter of the blood of *Lumbricus* is comparable chemically to that of a Vertebrate animal—like the dog. The spectrum of this colouring matter is identical with that of Vertebrate hæmoglobin.

Although hæmoglobin is present in the blood of certain Invertebrates, the chief constituent in the blood of the majority of these animals is hæmocyanin—a compound analogous to hæmoglobin, but containing copper instead of iron.*

* Concerning the *coagulation* of the blood of certain Invertebrates, the reader is referred to the important paper by Drs J. B. Haycraft and E. W. Carlier in the *Proc. Roy. Soc. Edin.*, vol. xv., p. 423.

A New Ship for the Study of the Sea. By His Serene Highness the Prince of Monaco.

(Read July 15, 1891.)

I had wished to render my visit to your country, which has always been in such sympathy with natural science, more interesting by the presence of a new scientific instrument—of a ship constructed entirely for scientific research; but, in spite of the best of wills, I have, after proceeding for several hours on the way to Edinburgh, been obliged to return to the Thames, in order to allow the builders to finish their work, in which they are unfortunately in arrear.

But it would have been very painful for me to give up this visit which promised me so much satisfaction, and I have come even without my ship to speak to you about her and to claim in advance your sympathy with its future work.

It is to do honour to Oceanography,—of that science whose field has only just begun to open itself to investigation,—that your society, one of the highest in the scientific world, has assembled to-day. And what is Oceanography? This is a question which, at the present time, may reasonably be asked by anyone of ordinary education, but it is one which will soon appear as strange as would be "What is Geography?" Yet Oceanography constitutes this most important department of Physiography, because it includes the study of the immense realm of the waters, with all the secrets which it can disclose to us of the past of our planet and of the conditions of its formation, while at the same time it can enlighten us on many points of its future. In fact this science includes in its programme the questions of the formation of the solid layers which, slowly deposited at the bottom of the ocean during thousands of centuries, are preparing under our eyes future continents; unless our earth be now too old to react as of old, when the material accumulated in the depths of its seas raised itself into subaerial mountains with all its fossil inhabitants, the faithful guardians of the secret of the great problem of the origin of life.

To establish the laws of Oceanography it is necessary to know the temperature, the motion, the chemical constitution, the density, and the zoology of the waters of the ocean at all depths. It is necessary to borrow a little from all the natural sciences. It is thus that Peter the Great appears to have first broken ground in the science, by having soundings made in the Baltic, the White Sea, and the Sea of Azof. Soon afterwards it was your countryman, James Cook, who, amongst the first, engaged in oceanographical research in one of his great voyages on board the "Resolution."

As is usual in the early stages of all sciences, the means at disposal were of the most primitive kind, and until your magnificent "Challenger" expedition, the observations collected in the course of numerous voyages, indicate much good will, without offering any of the precision or continuity of accurate observation, which are expected of the scientific observations of our time.

But the minds of the men who made these early observations gradually acquired a certain sagacity due to the contemplation of nature in the open, which it is difficult to acquire within the four walls of a laboratory, and without which great discoveries often remain barren.

It is thus that the great Darwin returned from his long voyage in the "Beagle" absorbed in the conceptions from which sprang the theories which threw a light on the scientific world as unexpected as would the rising of the sun in a new part of the horizon.

Nowadays the scientific men who forsake their laboratories for the open air are many, but the organisation of a scientific oceanic expedition is not easy. Sometimes the captain of the ship is not enough of a man of science to understand what science demands and to devote himself with the necessary zeal to it, he executes coldly the orders which he has received; sometimes it is the scientific men on board who are not sufficiently acquainted with the sea and life on board ship to be able to utilise their time to the best advantage of their scientific work. Owing to these causes, also, difficulties often arise between the captain and the scientific observers. Further, the keeping up of millions of men, the manufacture of hundred ton guns, and the launching of ironclads and torpedo vessels, do not leave much room in the budgets of most nations for intellectual work or for the labour of men who would

willingly devote themselves to the best interests of their fellow-men.

It was consequent on such reflections that, some seven or eight years ago, I undertook the mission which lay before me, because I was at once a sailor and devoted to science. The only means at my disposal, a sailing schooner of two hundred tons, was unfortunately much too restricted for the realisation of the enterprises which I dreamt of. But what can we not achieve when we are on the path of good and our whole heart is in it?

The "Hirondelle" was supplied in 1886 with several hemp ropes of different sizes for sounding and dredging and with a deep-sea trawl similar to that of the "Blake," and with a large iron pot and various sounding leads. With this material, worked by the arms of the crew, I made soundings, temperature observations, and dredgings in the Gulf of Gascony, down to a depth of five hundred metres. But the labour of these operations was considerable, and the crew were sometimes kept at the capstan for four hours at a time. And as the weather of that year was very bad there were series of twenty-five days during which it was impossible to leave off one's oil skins, for the trawl could be worked even in a heavy sea. In the intervals of work the 900 metres of dredge rope of the trawl, hardened by the water, and coiled all round the deck of the little schooner, rose like an oval wall above the heads of the men, who, always in the best of spirits, never murmured at the work, and even showed much intelligent curiosity in the results.

In the following years my working gear was much improved by the use of steel wire for sounding and dredging purposes, as also by the use of a special winch, still, unfortunately, worked only by the muscular exertions of my crew, and I was able to rectify many deficiencies in my methods of work; aided also by that will of success, which is the firmest support of workers, I succeeded in carrying my researches to a depth of 3000 metres round the Azores and off Newfoundland. But then, perfected in their training and stimulated by a certain pride, my crew worked as long as twenty hours at a stretch in dredging in 2800 metres. A pot similar to one which I had lost in moderate depths in 1886, when used with handier material, gave me magnificent results in depths of as much as 2000 metres, but this was always accompanied by very hard

work and continual calls on the imagination to surmount unforeseen difficulties as they arose.

During these expeditions, which extended over three years, I made experiments on the direction and velocity of the great surface currents of the Northern Atlantic, by means of 1700 specially loaded floats, which were thrown overboard in three distinct regions between Europe and America.

The results of these expeditions are being gradually published, and they show that the work done in the "Hirondelle" will leave a definite mark in the history of the science.

Zoology gains several hundreds of new species and genera spread over all its branches, as well as fresh knowledge about the geographical and bathymetrical distribution of certain animals; and this is due principally to the fact that I have applied systematically all the means of research at my disposal to one and the same region.

Oceanography will very shortly be enriched by a chart of the surface currents which I am preparing with the data furnished by the 224 floats which have been picked up out of the 1700 thrown over during my experiments. We have here a photograph on a reduced scale of this work which I am just finishing.

On this subject I shall confine myself to-day to pointing out that, possessing exact and authentic information on the positions of departure and arrival of a great number of these floats, which have come at first directly, and sometimes in numbers at a time, towards certain points of the coasts of Europe, I have been able during the six years which have passed to follow their successive appearances from the north of Sweden to the Canary Islands, then their return towards America, and even from some already, the repetition of this cycle. And thanks to these data which all afford mutual support, I have been able to construct my chart under conditions of exactitude which make of it an experimental document worthy of complete confidence as regards the general direction and the mean velocity of the currents of the North Atlantic. But if I remind you of these things to-day, it is to direct your attention to the fact that many of the privileged of fortune might easily contribute to the civilisation of humanity by elevating its intellectual power, if they would bring themselves into touch with the great efforts of science. The vast

domain of the sea is full of mysteries which the work of man will surely penetrate, and the collection of observations which enable *savants* to advance along this path would be a noble aim in the life of many people who weary themselves in the abundance of their goods, and wear themselves out in their uselessness.

To-day I am able to realise the plans which I have dreamed of so often, when, each year, during months of struggle with the sea, I could perceive treasures for science without the power of securing them. And I should have rejoiced to bring before you, the initiators of the great efforts made in this line, the god-parents of the Challenger, to bring before you my ship, the "Princesse Alice," the work of my waking thoughts and of my devotion to science. The Messrs Green of Blackwall, who have built her, may be proud of their work, and their skill has powerfully aided me in the realisation of my ideas.

The yacht "Princesse Alice" has a displacement of 650 tons, and I have only fitted her with auxiliary steam power in order to reserve as much space as possible for the arrangements necessary for engaging in serious scientific work, combined with the wants of social family life. Nevertheless, the engine-room is sufficiently large to accommodate various apparatus, which are thus under the management of one engineer; they are—a dynamo, an ammonia freezing-machine, and a water-still.

The dynamo supplies 100 lamps of 16-candle power for interior lighting, three 100-candle power lamps for lighting the deck when work is being carried on during the night, and a search light of 10,000 candles for illuminating the sea when work is being carried on in boats, and for picking up buoys.

The freezing-machine has several uses. By means of the liquefaction of ammonia gas, it produces a very low temperature, which is directly communicated to a liquid which does not freeze at this temperature, a brine which is then conveyed in tubes to the refrigerating chamber. This receptacle can contain several moulds of different forms and sizes to receive the objects which, for anatomical, histological, or zoological purposes, it may be wished to freeze, in order to protect them from the damage inseparable from the chemical processes at present in use. Once frozen, these objects will be placed in a cold chamber, kept at a temperature near that of

congelation by the refrigerating liquid which circulates in a coil of pipes close to the roof of the chamber.

The refrigerating chamber is placed in the central laboratory; the cold chamber is immediately below in the hold, where it occupies a space of about five cubic metres. A branch pipe takes the refrigerating liquid to the laboratory tables, to be used in delicate biological experiments. On the other hand, the cold chamber is large enough to accommodate a part of the ship's provisions.

The water-still is a "Yaryan" apparatus, very simple and powerful for its size, which furnishes $2\frac{1}{2}$ tons of fresh water per twenty-four hours for use in the boilers and the laboratories.

Several steam-engines are to be found at different points in the ship; a winch for working the dredge ropes and lighter lines for temperature and other observations is fixed to the deck in front of the foremast, and can lift 6 tons to a height of 1 metre in a second. A sounding-machine, which I have constructed on new ideas is fixed in front of the mizzen-mast; it acts automatically, and can indicate any depth to be found in the sea.

A large reel with two drums works in the hold. It carries on one side 6000 metres of cable in one length, to which a reserve of 4000 metres of stronger cable is ready to be joined for very great depths. On the other side there are 5000 metres of cable, divided into lengths of 500 metres.

The first will be used for dredging, the second for sending down pots, and generally for operations which require the apparatus used to remain at the bottom of the sea for a time, while the cable is buoyed. Finally, there is another small double reel, which is very light, and carries pieces of cable varying from 100 to 500 metres in length, which are used for small operations, for which it would be useless or inconvenient to use longer pieces.

To summarise, the actual equipment of the ship allows of sounding everywhere, dredging in 8000 metres, and laying out pots or other apparatus on the bottom at depths up to 6000 metres without the least difficulty.

The stoke-hold is arranged in a way suitable to the equipment of the ship. It contains two boilers, a small and a large one. The first is used to drive the auxiliary machines (winch, dynamo, &c.), and when applied to the main engines can drive the ship three

knots per hour; the second, along with the first, gives a speed of nine knots. Thus the ship can be economically steamed slowly while work is being carried on, and she can also be worked under sail when the wind permits.

The products of the scientific work are distributed amongst three laboratories, as follows:—

The materials as collected are received in a laboratory situated on deck abaft the mainmast, and communicating by a lift with the central laboratory immediately below, and the lift descends as far as the cold chamber in the hold. After a first picking over, for the elimination of useless matter, the zoological material is sent to the central laboratory, and the oceanographical material to a third laboratory in the after part of the ship, which is devoted to chemistry and physics. These laboratories are lighted by large *scuttle lights*, and the arrangement of the tables allows of four or five persons working at each of them without interfering with one another. Like the rest of the ship, they are heated by steam on a special system. As to the general service of the ship, it is arranged according to what modern progress has recognised as most useful and most practical.

I do not think that one ought to carry too far an analysis or other delicate observations during the voyage. The movement and the noise, however subdued they may be, are a cause of constant disturbance; on the other hand, one would have to have exceptional power over one's mind, to be able to arrest it in the exciting moments of a general investigation, whilst other experiments, of an engrossing character, were being carried on without interruption, on the largest scale and with full power of the ship.

To follow out under these conditions any profound idea does not seem to me to be an easy matter, and I think that it ought to be one's chief object, during the work at sea, to make the best arrangements for collecting a great number of facts at the most favourable moments, and for noting all the details which strike the eye and the mind. It is thus that a painter makes a study from nature, which afterwards becomes a masterpiece, when the impressions he has received have matured in the silence of the studio.

And now I regret that I must terminate this communication to the Royal Society very differently from what was originally my intention, viz., without being able to invite you to visit the

new ship which I should have been proud to show to men such as Sir William Thomson, John Murray, Buchanan, Buchan, and to the intelligent cultivators of science who fill this room. I could then have justified the flattering reception which you are giving me; but in the hope of repeating at a later date, and under perfectly satisfactory conditions, this visit to the scientific representatives of Edinburgh, who will form the best judges of my future work, I thank you cordially for your very kind attention.

The Electric Resistance of Cobalt at High Temperatures. By Professor Cargill G. Knott, D.Sc., F.R.S.E. (With a Diagram.)

(Read July 6, 1891.)

The manner in which the electric resistance of cobalt varies with high temperatures does not seem to have been studied with any great care. The peculiar behaviour of iron and nickel as regards their change of resistance with temperature is now well known.* With a view to discover if cobalt presented any similar peculiarity, I set Mr Ōmori, one of the physical students in the Imperial University, Japan, to investigate the question. The chief results are embodied in the present short paper.

The piece of cobalt used was cut from a sheet of rolled cobalt which had been given me by Professor Tait. Dr E. Divers, F.R.S., very kindly determined its composition by analysis of a small quantity (about 20 grains) supplied to him. The result of the analysis is as follows :—

Carbon found, ...	0·77 per cent.
Silicon, ...	0·15 ,,
Iron, ...	0·73 ,,

with a minute quantity of manganese and perhaps $\frac{1}{10}$ per cent. of a metal undetermined. The carbon might be as much as 1 per cent. Dr Divers regarded the cobalt as of remarkable purity for a furnace product.

The experiments now to be described were carried out in January and February of 1890. The method was essentially the same as that used in my earlier investigations on nickel. Four stout copper rods, 60 cm. long, 0·7 square cm. cross-section, were fixed in a vertical position some little distance apart. Their lower extremities were joined in pairs by two coiled wires, one of which was a

* See my paper "On the Electric Resistance of Nickel at High Temperatures," *Trans. Roy. Soc. Edin.*, vol. xxxiii., 1886.

specimen of platinum wire and the other the cobalt strip that was the special object of investigation. The upper extremities of the rods were joined by stout copper strips to a commutator connected to a Wheatstone Bridge resistance-box of ordinary construction.

In one series of experiments the lower ends of the rods with their connecting wires were dipped in a vessel of oil which could be heated up to a temperature of 240° C. A thermometer, centrally placed so that its bulb lay at the mean level of the platinum and cobalt coils, was used for measuring the temperature. The oil was heated very gradually and was kept briskly stirred until a few seconds before a reading was to be taken. One of the wires was meanwhile thrown into the Wheatstone Bridge, and the resistance adjusted slightly in advance. The temperature was then allowed to rise very slowly until reversal of the commutator in the galvanometer branch gave no deflection. When the equilibrium was thus attained the thermometer reading was noted. In this experiment chief attention was given to the cobalt; a few measurements of resistance were made with the platinum, sufficient to give the most important temperature coefficient.

The resistance curves for the cobalt and the platinum are shown in the diagram, Nos. 1 and 2. All corrections have been carefully applied and the resistances are in legal ohms.

By interpolation amongst a number of contiguous measurements, the resistances corresponding to the temperatures 100°, 140°, 180°, and 220° C. were calculated. They are given in Table I., together with the measured resistance at the temperature of the air.

TABLE I.—*Resistance of a Cobalt Strip in Legal Ohms at Different Temperatures.*

Temperature.	Resistance.	First Diff.	Ratio.
7°·5 C.	0·09604		
100	·12340		
140	·13694	·01354	1·1097
180	·15210	·01516	1·1109
220	·16859	·01649	1·1084

Since the second differences have appreciably different values, it is impossible to represent the law of change by means of a parabolic function. But the remarkable constancy of the ratios of successive pairs of resistances suggests an exponential function of the temperature as the expression for the resistance.

Thus we may put,

$$r = a\epsilon^{kt}$$

from which we find, if t is the temperature in degrees centigrade,

$$k = \cdot 002605 \qquad a = \cdot 09511$$

According to this formula, which strictly applies only to temperatures above 100°, the resistance at 7°·5 should be ·09698, almost exactly 1 per cent. too high.

In the paper already referred to, I found that the same form of expression held very approximately for the case of one of the nickel wires, the only essential difference being in the value of k, which for nickel was ·003. The resistance of cobalt therefore does not change so quickly with temperature as does the resistance of nickel.

In the second series of experiments, the lower ends of the rods, with their connecting wires, were inserted into a porcelain vessel. Asbestos was wrapped round the wires; and the whole was heated in a charcoal furnace. The observations of resistance were made as the system was cooling, the cobalt and platinum being thrown alternately into the Wheatstone Bridge. The instants at which the balancings were effected were carefully noted, so that it was an easy matter to interpolate between two successive measurements for the one wire that resistance which corresponded to the intermediate measurement for the other wire. In this way, for every measured cobalt resistance, the corresponding resistance of platinum was calculated by a simple interpolation. After all corrections were applied, every resistance was divided by the resistance of the same wire at 7° C. By this treatment the results of the four different experiments were reduced to identically the same condition, so that direct comparison was possible.

Each single experiment contained from 20 to 30 distinct pairs of measurements. These numbers were then classified into groups,

and by a rigorous process of interpolation, the cobalt resistances corresponding to assumed values of the platinum resistances were calculated. These are the numbers given in Table II., which epitomises the results of the four distinct experiments. The first column contains the platinum resistances, taken as convenient multiples of the resistance at 7° C., measured *after* the experiment. These virtually serve as a temperature scale. The other columns give in order the corresponding resistances of the cobalt, likewise all expressed in terms of the cobalt resistance at 7° C., measured *after* each experiment.

TABLE II.

Platinum Resistances.	Cobalt Resistances.			
	Experiment I.	Experiment II.	Experiment III.	Experiment IV.
2·0	5·8047	5·7996	5·9748	6·0361
1·8	4·5101	4·3423	4·4511	4·4580
1·6	3·1822	3·0536	3·0932	3·2216
1·4	2·2029	2·1795	2·1111	2·2602
1·2	1·5329	1·5337	1·5050	...
1·0	1·0000	1·0000	1·0000	1·0000

If we assume that the changes in the platinum resistance follow the same law as in the earlier experiment with the oil, the rise of temperature, which will just double the resistance, is about 680° C.; and the interval from 1 to 1·2 may be taken as corresponding to a rise of temperature of 136° C. According to the experiment in oil, this rise of temperature would have increased the resistance of the cobalt in the ratio 1·425 to unity. It is apparent then, that under the influence of the first excessive heating, the cobalt has been considerably altered in its properties, so that the average temperature coefficient for resistance up to 150° C. has been increased by a quarter. The only other possible explanation of this discrepancy is that the corrections to be applied for the resistances of the connections or contacts may have been underestimated in the second series of experiments, or overestimated in the first. There could, however, be no doubt as to the resistances of the connections, which were the same in

all experiments, and were measured with great care. If again the resistances of the contacts had changed to any great extent, this would declare itself in the measured resistances at 7° C. made before and after the first severe heating. In Table III. these measured resistances, corrected for connections, are given. They were all made at 7° C., except the first pair (taken immediately before the first heating), for which the temperature was 7°·5 C.

Table III.

Resistance in Legal Ohms of		When measured.
Platinum.	Cobalt.	
·8525	·09724	Before 1st heating.
·85028	·09135	After 1st ,,
·85028	·09354	,, 2nd ,,
·85013	·09674	,, 3rd ,,
·85232	·09978	,, 4th ,,

The fall in resistance after the first heating is probably due to some change in the contact resistances—decrease evidently. But even if this were large enough to sensibly affect the second significant figure in the calculated value of the temperature coefficient, its effect would be to diminish this coefficient. Consequently, we must accept the conclusion that the first excessive heating has profoundly influenced the qualities of cobalt as regards its change of resistance with temperature.

Table III. shows us also that whereas the platinum resistance at 7° C. has not been changed at all by the second heating, and only slightly by the third, the cobalt resistance goes on steadily increasing. After the experiments were completed, the cobalt was indeed found to be much altered by oxidation. It had become exceedingly brittle, and broke into small pieces when it was being detached from the copper rods. This steady deterioration in condition of the cobalt explains the inferiority in point of regularity of the third and especially the fourth experiment, as compared with the first and second.

It is matter of surprise that, in spite of the great alteration in structure taking place in the cobalt strip, the general behaviour of

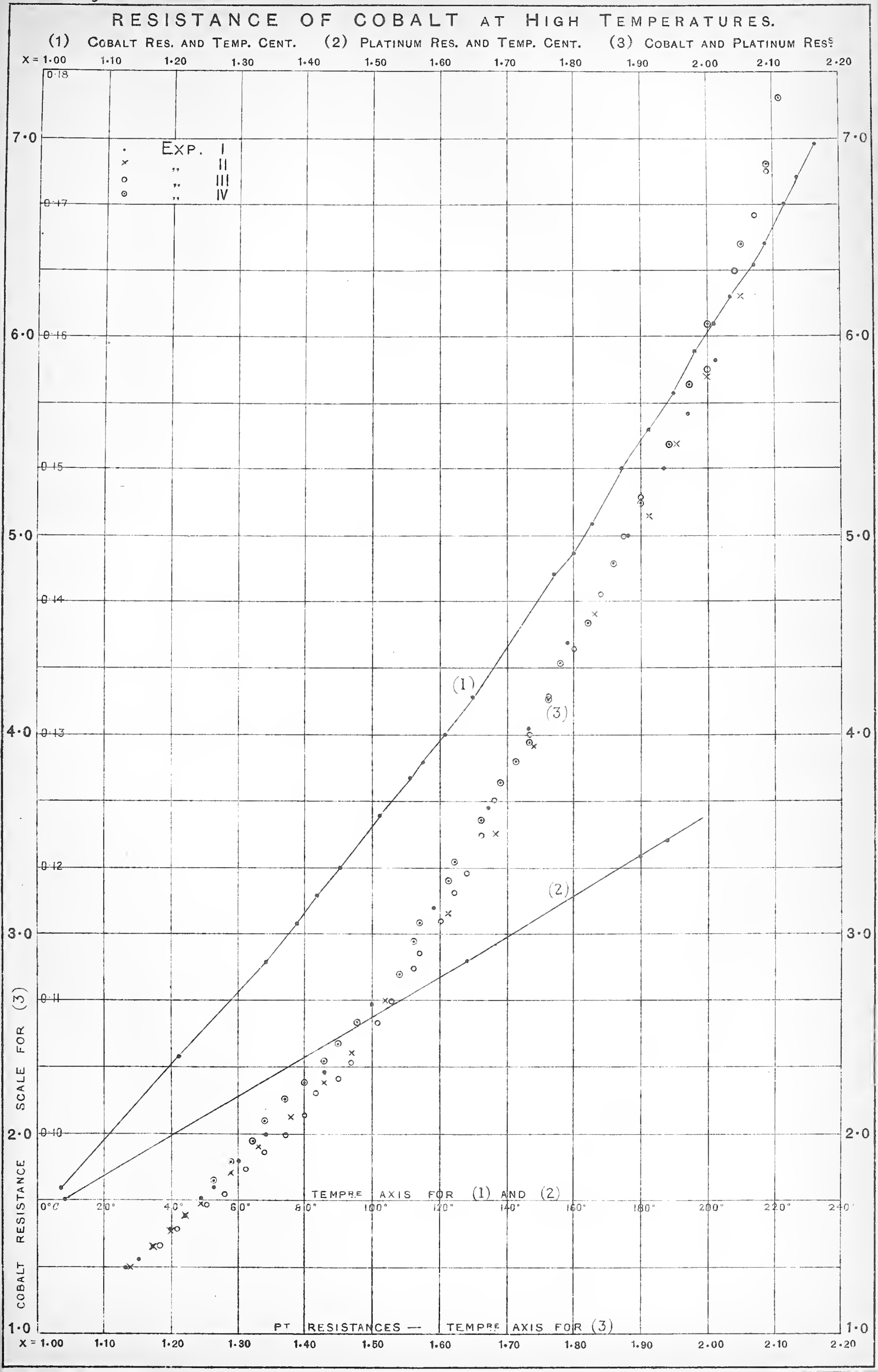
the cobalt, as shown in the first three experiments, is essentially the same. This is well shown by tabulating the rates of change themselves. These quantities were calculated from the observations by the same general method of interpolation as was used in calculating the numbers of Table I. They are given in Table IV., of which the first column contains the platinum resistances to which the tabulated rates of change correspond.

TABLE IV.

Platinum Resistance (or Temperature).	Rates of Change of Cobalt Resistance per Unit Change of Platinum Resistance.			
	Experiment I.	Experiment II.	Experiment III.	Experiment IV.
2·0	7·02	7·30	10·33	9·15
1·8	6·19	7·24	6·74	5·09
1·6	5·45	5·57	6·63	6·10
1·4	3·76	3·58	3·65	3·66
1·2	3·58	3·23	2·78	...

I have thought it sufficient to give the condensed numerical results as contained in Tables I., II., and IV. The individual observations upon which these results are based are entered graphically in the diagram. Curves 1 and 2 have already been mentioned. They show the march of resistance with temperature as measured on a mercurial centigrade thermometer. In curve 3, the platinum resistances are the abscissæ, and the ordinates are the corresponding cobalt resistances. The points belonging to the various experiments are distinguished by special mark.

In one particular, cobalt resembles iron and nickel in its behaviour. There is a rapid increase in the steepness of the curve at higher temperatures. In iron and nickel, however, this rapid increase is followed at still higher temperatures by a distinct decrease, the curves bending so as to present a concavity towards the temperature axis. Neither Table IV. nor the curves give any hint of such a tendency in cobalt. It will be seen that Experiments I. and II. are in fair agreement throughout; and that all four experiments point to the existence of a critical temperature at which the re-


RESISTANCE OF COBALT AT HIGH TEMPERATURES.
(1) COBALT RES. AND TEMP. CENT. (2) PLATINUM RES. AND TEMP. CENT. (3) COBALT AND PLATINUM RESS
x = 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10 2.20
· EXP. I
× ,, II
○ ,, III
⊙ ,, IV
0.18 0.17 0.16 0.15 0.14 0.13 0.12 0.11 0.10
7.0 6.0 5.0 4.0 3.0 2.0 1.0
(1) (2) (3)
TEMPRE AXIS FOR (1) AND (2)
0°C 20° 40° 60° 80° 100° 120° 140° 160° 180° 200° 220° 240°
COBALT RESISTANCE SCALE FOR (3)
PT RESISTANCES — TEMPRE AXIS FOR (3)

sistance begins to increase rapidly with rise of temperature. This critical temperature is about the stage 1·5, which corresponds approximately to 350° C. The phenomenon may be broadly stated in these terms. Between temperatures 400° C. and 700° C. the resistance of a cobalt strip increases on the average at a rate nearly twice as great as the average rate of increase between 0° and 300° C.

The Thermoelectric Positions of Cobalt and Bismuth.

By Professor **Cargill G. Knott**, D.Sc., F.R.S.E.

(Read July 6, 1891.)

So far as I know, the only satisfactory determination of the position of the cobalt line on the thermoelectric diagram was made by Professor Tait's students in the Physical Laboratory of Edinburgh University some fifteen years ago. The position of the cobalt line, so found, was given along with the positions of certain alloys in a paper by Professor J. Gordon MacGregor and myself, published in the *Transactions of the Royal Society of Edinburgh*, vol. xxviii. (1878). The particular specimen of cobalt used in these early experiments was a short rod obtained by electrolytic decomposition. The noteworthy facts regarding its thermoelectric line were that it lay below nickel on the diagram, and that its inclination to the lead line was much greater than the inclinations of the iron and nickel lines.

As a laboratory exercise, I gave to Mr Sawada, one of our students of physics, the task of studying the thermoelectric properties of the cobalt described in the preceding paper on electric resistance. The plan adopted was to form a multiple arc of palladium and bismuth, and, by proper adjustment of the resistances in these branches, to obtain an intermediate line which should cut through the cobalt line at temperatures within easy reach.

Such an intermediate line passes through the neutral point of the component metals. It divides the region between their lines so that any transversal is cut into portions which are directly as the resistances in the branches of the multiple arc. Thus, by varying the ratio of the resistances in these branches, we may sweep through the region between the two corresponding diagram lines, interpolating, so to speak, any intermediate line suitable for our purpose. The extreme accuracy with which we can measure electric resistance enables us to fix the position of this intermediate line as accurately as the positions of the component lines are known.

In the present case, the low position of cobalt on the diagram very much circumscribed the choice of metals for the multiple arc.

Bismuth had to be one of them, as it alone was known to lie below cobalt. The other metal fixed upon was palladium, a substance convenient in every way. Its diagram line is straight up to high temperatures; and its character does not perceptibly change even after severe heatings. Unfortunately, however, the use of bismuth limited the investigation to moderate temperatures only.

The bismuth was broken up into small pieces, which were packed tightly into the bore of a siphon-shaped glass tube. Gentle heating in a Bunsen flame sufficed to melt the metal, which ran together and solidified on cooling into a fairly uniform rod. The junction wires were fused into the ends of the bismuth rod.

As finally set up, the apparatus consisted of a triple cobalt palladium bismuth junction dipping in oil. This formed the "hot junction." Resistance boxes were included in the palladium and bismuth branches. Because of the magnitude of the thermoelectric forces between these three metals and copper, great precaution was necessary in keeping the various cold junctions at the same temperature. The palladium branch always contained 100 ohms resistance; and the bismuth branch never contained less than 200. For each of the seven selected ratios of resistance, a careful series of thermoelectric observations was made. A delicate high-resistance galvanometer was used; and the temperatures were measured by a mercurial thermometer. The electromotive forces between the cobalt and each intermediate "equivalent metal" were in this way measured directly. From these the thermoelectric powers at chosen temperatures could be calculated. But one of these equivalent metals was palladium itself, obtained by making the resistance of the bismuth branch infinite. Thus, by a simple process of subtraction, we obtained the thermoelectric powers between palladium and all the others. These quantities, calculated for 0° and 100° C., are given in the following table. The symbols Bi, Co, Pd stand for the metals bismuth, cobalt, and palladium respectively. The various equivalent metals are represented by the symbol Pd Bi_n, where the number n represents the ratio of the resistances in the bismuth and palladium branches. Thus Pd Bi_2 means that, since the palladium branch always contained 100 ohms, the bismuth branch contained in this case 200 ohms. The electromotive forces, from which these values were calculated, were measured in microvolts.

Thermoelectric Powers referred to Palladium.

Metal.	Thermoelectric Power at 0° C.	Thermoelectric Power at 100° C.	Neutral Point with Cobalt.
Co, ...	7·00	17·31	...
Pd Bi_{13}, ...	5·98	6·46	−10°·4 C.
Pd Bi_8, ...	9·38	9·96	+24°·5
Pd Bi_5, ...	14·45	14·69	74°·1
Pd Bi_4, ...	17·44	17·44	101°·4
Pd Bi_3	21·73	22·13	148°·9
Pd Bi_2	29·10	29·55	224°·0
Bi, ...	86·0	88·8	...

The numbers in the last row have been calculated from the numbers in all the six Pd Bi rows. For if p is the thermoelectric power between Pd and Bi, and p_n the same between Pd and Pd Bi_n, we know that

$$\frac{p-p_n}{p_n}=\frac{n}{1},$$

or

$$p=(n+1)p_n.$$

Thus, from the six sets of values corresponding to p_n we obtain the following values for p at 0° C. and 100° C. :—

$n+1$.	p at 0° C.	p at 100° C.
14	83·7	90·4
9	84·4	89·6
6	86·7	88·1
5	87·2	87·2
4	86·9	88·5
3	87·3	88·7
Means, . .	86·0 0·8	88·8 0·7

This table is obviously an indication of the accuracy of the experiment.

And now, referring everything to the lead-line, and expressing the thermoelectric power in the form

$$p=A+Bt,$$

we obtain for the coefficients A and B the following values:—

	A	$B.10^2$.
Lead, ...	0	0
Palladium, . . .	− 6·18	− 3·55
Cobalt, . . .	−13·18	−13·9
Bismuth, . . .	−92·2	− 6·4

According to the numbers deduced by Fleeming Jenkin from Matthiesen's experiments, bismuth lies four times further from lead than does cobalt. Here we have it seven times. Professor Tait's electrolytically-deposited cobalt lies four and a half times further from lead than does palladium. Here we have it a little over two times. According to Becquerel's numbers, given at the end of the English translation of Mascart and Joubert's *Electricity and Magnetism*, the ratio at 50° C. of the thermoelectric powers of palladium and bismuth relatively to lead is as 7 to 40. Here we have it 1 to 16.

These discrepancies are not surprising. We know* how variable are the thermoelectric properties of stable alloys intended to have the same composition, and how a very slight change in composition may be accompanied by a very large change in thermoelectric quality. The present experiments must therefore be judged of altogether on their own merits. Now, a simple comparison shows that Professor Tait's electrolytically deposited cobalt will fit in to the region between lead and bismuth very much as Matthiesen's cobalt fits in to his own series. Thus the cobalt investigated here seems to differ from the other specimens in much the same way. The new cobalt, indeed, has its diagram line at ordinary atmospheric temperatures *above* the line of Tait's nickel, for which $A = -21·8$. This unexpected result was at once tested. A rough experiment was made with a nickel cobalt couple, and a neutral point was obtained at a moderately low temperature. The cobalt line, therefore, begins above the nickel line, but because of its greater downward inclination gets below it at temperatures above 100° C.

* See the paper by MacGregor and myself, already referred to; also my paper on "The Electrical Properties of Hydrogenised Palladium" (*Trans. Roy. Soc. Edin.*, vol. xxxiii., 1886).

As regards the inclination of the cobalt line, the present result agrees as well with the earlier result as could reasonably be expected with two quite different specimens of the metal. Thus, expressed in the same units, the thermoelectric power of Tait's electrolytically-deposited cobalt is

$$p = -26{\cdot}3 - 0{\cdot}116t,$$

while for the present specimen

$$p = -13{\cdot}2 - 0{\cdot}139t.$$

With the exception of the sharp upward bend in nickel, this gives the greatest inclination yet obtained for a thermoelectric line.

The downward trend and comparatively large inclination of the bismuth line are also worthy of note. Because of the position of the line, as a whole, lying far below the lines of all other metals, this large inclination does not greatly influence the electromotive forces, so that with bismuth couples the electromotive force is very approximately proportional to the temperature. This fact, of course, prevents us from making a very accurate determination of the coefficient B, which in the present experiment has a large probable error. The mean value is a little larger than that indicated by Battelli's direct measurements of the Thomson effect in bismuth.*

Righi has shown† that the electric resistance of bismuth is altered in a strong magnetic field. To find if any thermoelectric change accompanied magnetisation of bismuth, a bismuth palladium couple was set up between the poles of a powerful electromagnet. No effect whatever was observed, although the arrangement (slightly modified) was sensitive enough to show with great ease the thermomagnetic effect discovered by v. Ettingshausen and Nernst.‡

* See *Wied. Beibl.*, vol. xi., 1887. † See *Wied. Beibl.*, vol. viii., 1884.
‡ See *Wied. Ann.*, vol. xxix., 1886.

On the Effect of Longitudinal Magnetisation on the Interior Volume of Iron and Nickel Tubes. By Professor Cargill G. Knott, D.Sc., F.R.S.E.

(Read July 20, 1891.)

The following results in magnetic strains are, so far as I am aware, new. They supplement in an interesting way Joule's old result of no change of volume in an iron rod when it is magnetised. What is given here is only preliminary, and suggests many lines of research which I hope to be able to follow out later.

The broad fact established is, that the internal capacity of certain iron and nickel tubes alters appreciably when the tubes are magnetised longitudinally. The tubes were 34·8 cm. long, and were all about 3 cm. external diameter. One iron tube had an internal diameter of 1 cm., and another of 2 cm. These I shall call A_1 and A_2 respectively. A_3 represents the third iron tube, whose wall was about 1 mm. thick. The nickel tube (B) had its wall 0·3 mm. thick. When experimented with, each tube was tightly corked at both ends, and through the one cork a fine capillary glass tube projected. The tube was filled with alcohol coloured with cochineal. The changes of volume were measured by the movement of the end of the liquid column in the capillary tube. This was viewed through a microscope. A movement in the tube through a distance equal to one division of the microscope micrometer meant a change of volume of $7{\cdot}2 \times 10^{-6}$ cub. cm.

As an example, take the case of A_1, the small bored iron tube, in a field of 250. The sudden outward movement of the liquid meniscus showed a total compression (change per unit volume) of 21×10^{-7} in the region inside the tube. But we know that in this field ordinary wrought iron lengthens; and in virtue of this lengthening the internal volume will be increased. It is clear, then, that the transverse contraction of the walls of the tube has overbalanced the longitudinal extension. If $\lambda\ \mu$ represent the elongations parallel to and perpendicular to the axis of the tube along the inner surface of the bore, the dilatation will be $\lambda + 2\mu$. Now, in field 250 Bidwell

finds $\lambda = +5 \times 10^{-7}$; hence at once $\mu = -13 \times 10^{-7}$. I give a few results for the different tubes in various fields.

In Field 50.

Tube.	$\lambda + 2\mu$ observed.	λ Bidwell.	μ calculated.
A_1	$-1{\cdot}84 \times 10^{-7}$	$+10 \times 10^{-7}$	$-5{\cdot}9 \times 10^{-7}$
A_2	$-2{\cdot}1$,,	,,	$-6{\cdot}1 \times 10^{-7}$
A_3	$-1{\cdot}2$,,	,,	$-5{\cdot}6 \times 10^{-7}$

In Field 125.

Tube.	$\lambda + 2\mu$	λ	μ
A_1	$-6{\cdot}6 \times 10^{-7}$	$+18 \times 10^{-7}$	$-12{\cdot}3 \times 10^{-7}$
A_2	$-8{\cdot}4$,,	,,	$-13{\cdot}2 \times 10^{-7}$
A_3	-3 ,,	,,	$-10{\cdot}5 \times 10^{-7}$

In Field 250.

Tube.	$\lambda + 2\mu$	λ	μ
A_1	-21×10^{-7}	$+5 \times 10^{-7}$	-13×10^{-7}
A_2	-7×10^{-7}	,,	-6×10^{-7}
A_3	$-2{\cdot}6$,, ?	,,	$-7{\cdot}6 \times 10^{-7}$

Unfortunately I possessed no nickel tubes shaped like the iron ones, so had to content myself in the meantime with a thin walled tube formed by rolling up a sheet of ordinary commercial nickel to the convenient size. The results for this tube were of great interest. Up to a field of 50, the *compression* of the inside space varied uniformly with the field, the dilatation being given by the formula

$$\lambda + 2\mu = -1{\cdot}8 \times 10^{-8}H,$$

where H is the longitudinal field. Now Bidwell's results give up to the same field the following expression for λ:—

$$\lambda = -18 \times 10^{-8}H.$$

Hence

$$\mu = +8{\cdot}1 \times 10^{-8}H.$$

For fields higher than 50 the following remarkable results were obtained :—

Field.	$\lambda + 2\mu$	λ	μ
60	$-9{\cdot}7 \times 10^{-7}$	-100×10^{-7}	$+\ 45{\cdot}7 \times 10^{-7}$
100	$-8{\cdot}0$,,	-140 ,,	$+\ 66$,,
135	0	-163 ,,	$+\ 81{\cdot}5$,,
240	$+4{\cdot}0$,,	-190 ,,	$+\ 97$,,
260	$+9{\cdot}0$,, ?	-202 ,,	$+105{\cdot}5$,,

Thus, for the iron tubes, the transverse contraction always exceeds the longitudinal extension, so that there is on the whole a diminution of the internal space. There is evidence of the contraction attaining a maximum, which, in the case of the thinner walled tubes (A_2 and A_3), occurs in a field not far removed from the field which produces the maximum extension.

For the nickel tube, the transverse *expansion* differs so slightly from the longitudinal contraction, that the change of volume of the internal space, though of the same order of quantity as the corresponding change in the iron tubes, is a very small fraction indeed of the change that would result from the longitudinal contraction acting alone. In low fields, the longitudinal contraction overbalances the transverse expansion, causing a compression. This compression reaches a maximum about field 60, and then falls off first slowly, then more rapidly. About 140 it becomes zero, and changes sign in higher fields. In field 260 a very distinct dilatation is produced about equal to the maximum compression obtained in field 60. The rapid changes of temperature of the liquid in the heart of the magnetising coil, when the high currents were used, made accurate measurements of the changes of volume impossible; but there was no doubt as to the fact of the change of sign in the compression when the field was taken high enough.

It should be mentioned that, in an experiment with a glass tube substituted for the iron or nickel tube, no effect was produced; so that the alcohol itself was uninfluenced by the magnetising force. An experiment was also tried with a current of seven amperes passed along the iron tubes, so as to cause a circular magnetisation of the outer circumference. No change of volume was observed, however, probably because of the comparative smallness of the fields involved.

On some Relations between Magnetism and Twist. Parts II., III.

By **Cargill G. Knott**, D.Sc. Edin., F.R.S.E., *Professor of Physics, Imperial University, Tokyo, Japan.*

(Read June 1st, 1891.)

(*Abstract.*)

Part II. contains a continuation of former experiments on the twists produced in the magnetic metals when they are under the combined influence of circular and longitudinal magnetisations.

It is established that a cobalt rod of rectangular section twists left-handedly when a current is passed along it in the direction of magnetisation. That is, cobalt behaves like nickel. Iron, on the other hand, twists right-handedly, until very high fields are employed. These results seem to have a close connection with the magnetic changes of length in these metals; for iron expands in moderate fields, while nickel and cobalt contract, the former always, and the latter till high fields are reached.

In the case of nickel an evident maximum twist is obtained for intermediate values of field. The occurrence of this maximum finds a ready explanation in terms of the theory suggested.

In all cases the amount of twist produced by reversing one of the magnetising forces depends on which one is reversed. Generally the twist is greater when the longitudinal field is reversed than when the current along the wire is reversed. For low fields in the case of iron and nickel it is, however, the current reversal that produces the greatest twist. These various phenomena give very instructive illustrations of the magnetic after-effect or hysteresis.

In Part I. an expression was given for the twist in terms of the elongations in a thin walled tube of given radius, under the combined influence of given circular and longitudinal magnetisations. From the observed maximum twists in iron and nickel wires now given, a comparison is made between the elongation coefficients which enter into the formula for the tubes of equal diameter. The comparison is in remarkable accordance with the direct comparison of elongations as furnished by Mr Bidwell's measurements.

Part III. contains a discussion of the magnetic consequences of

twisting a magnetised wire, more especially a wire magnetised circularly by a current passing along it. The peculiar manner in which the magnetic change sometimes lags behind the stress, sometimes shoots ahead of it, is fully investigated. This magnetic "lagging" or "priming" is found to depend upon the strength of the current, upon the amount of twist, and upon the amount and degree of tapping to which the wire is subjected.

The longitudinal polarity acquired by a current-bearing wire when it is twisted is relatively very high as compared with the probable intensity induced at the circumference of the wire. Further, the longitudinal intensity so acquired is reversed, more or less completely, when the current is reversed. These facts are not easily explained in terms of the usual theory of magnetic æolotropy, or in terms of any simple hypothesis of rotatable molecules. They rather hint at the existence of complex molecular groupings, which assume new configurations under the influence of a changing stress or a changing magnetic force.

Certain experiments on the effect of slightly twisting a wire, which by superposed magnetisms has been reduced to an apparently demagnetised condition, show how easy it is to destroy the apparent magnetic balance. There is a strong suggestion that a magnetised wire may, under certain circumstances, consist of alternating layers of opposite polarities. Any mechanical stress which acts differently on these different layers will almost, as a matter of course, powerfully affect the average resultant action which is measured on the magnetometer.

From the experiments recorded in the paper, and from the experiments of other investigators into the complex relations of magnetism and twist, the general conclusion may be drawn that the first effect of a shearing stress upon the molecular groupings is not only to increase the average intensity in the direction of the magnetising force, but also to bring into prominence a relatively high intensity in directions at right angles thereto.

On the Gravimetric Composition of Water. *A Preliminary Communication.* By W. Dittmar.

(Read February 3, 1890.)

On the strength of Dumas' famous *Recherche sur la Composition de l'Eau*,* and adopting the great master's own interpretation of his results, all chemists, until lately, agreed in assigning to the atomic weight of oxygen the value $O = 16$ $(H = 1)$; and it is on the strength chiefly of the same experiments that many of us now hold that $O = 15{\cdot}96$ is a closer approximation to the truth!

In these circumstances it surely is worth while to look into Dumas' work with the help of critical experiments, and try to see whether he was not right in thinking that—all his great efforts notwithstanding—the difference lies within the influence of his *method*-errors; the more so, as all these errors (as far as one can see without experimenting) tend to raise the experimentally ascertained value of the ratio H : O above its true value.

I accordingly, some time ago, caused my private assistant, Mr Henderson, to join me in this inquiry, and, thanks to his youthful energy and indefatigability, we have already made considerable progress in our work, and hope before long to lay a complete account of it before the Society. Meanwhile, I content myself with stating that we have succeeded in so modifying Dumas' *modus operandi* as to give a higher degree of constancy to the weighings, and to reduce the trouble and loss of time involved to far less than it was with the original form of the method.

The principal object of the present notice, however, is to direct attention to an oversight which Dumas made himself guilty of, and which, as far as I am aware, has never been noticed before. What I allude to is that Dumas, while weighing his oxygen (virtually) *in vacuo*, weighs his water in air, and forgets to reduce this latter weight to the *vacuum*.

That the correction tells very considerably upon the calculated weight of the *hydrogen* a very little reflection is sufficient to show;

* *Ann. Chim. Phys.* (3), vol. viii. p. 189.

I prefer to give at once the results of my recalculation of Dumas' experiments, and apply the correction to the most "probable value" as calculated by me.

In his tabular statement of results Dumas gives, in the case of each of his nineteen experiments, two values for what he calls the "equivalent of hydrogen" (the term with him meaning the weight of hydrogen which combines with 10,000 parts of oxygen into water)—viz., firstly, the value as calculated from the uncorrected weights of water and oxygen; and, secondly, the "*equivalent* * *as corrected for the air in the sulphuric acid*" (used for the evolution of the hydrogen from zinc). For reasons, which will be stated in the memoir, I have left these corrected values on one side, and recalculated and reduced only the "*equivalents bruts.*"

Taking S as a symbol for the weight of oxygen consumed in a given experiment, and W for the uncorrected weight of water produced, I formed the equations

$$W_1 - kS_1 = \delta^1$$
$$W_2 - kS_2 = \delta_2$$
$$W_3 - kS_3 = \delta_3$$
$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

and solved the nineteen equations in respect to k—firstly, in the way which reduces the algebraic sum of all the errors δ to nil; and, secondly, so as to reduce the sum of the *squares* of the errors δ to its *minimum.* The first method gave $k = 1{\cdot}125\ 43$; the second gave $k = 1{\cdot}125\ 47$.

The two values, as we see, are practically identical. Adopting the second, it may be read as stating that 1000 grammes of oxygen take up hydrogen to form a quantity of water whose apparent weight in air is 1125·47 grammes. But, assuming the air to have the density corresponding to 15° and 760 mm. (which probably is not far removed from the air-density which actually prevailed during Dumas' work), the air displaced by the water amounts to 1·38 grammes; hence we have, in reference to any given quantum of water, the following relative values for the weights of

* As already pointed out by Lothar Meyer and Seubert, Dumas' table of results includes quite a number of misprints. These, however, are all easily discovered, and set right without much fear of error.

Oxygen.	Hydrogen.	Water.
1	0·126 85	1·126 85
8	1·014 8 = "H"	
15·767 = "O"	2 = "H_2"	

The results of our own work enable me to say that the true value of "H" (O = 16) is probably not quite so high as 1·0148, but it is higher than the 1·0024 demanded by the customary "O = 15·96."

I venture to hope that the publication of this notice will cause those chemists who hitherto (*after* having become convinced that O : H is less than 16) have persisted in referring their atomic weights to H = 1, will give up this absurd practice, and, like other people, adopt O = 16 as their standard. The sixteenth part of the atomic weight of oxygen, surely, is as good a unit as one could desire to have.

Investigation of the Action of Nicol's Polarising Eye-Piece. By E. Sang, Esq. (With a Plate.)

(Read February 20, 1837.)

The first announcement of the construction of this important instrument appeared almost paradoxical: a piece of calcareous spar was to be cut in two, the surfaces of the section polished, and then reunited by help of Canada Balsam: and it seemed strange that from such an operation there should have resulted any change in the optical properties of the mass. Even now that the instrument has been in use for some time, the true nature of its performance is often misunderstood; while no investigation has been made public, the object of which is to enquire into the laws of the action, and into the circumstances which determine the peculiar forms of the parts.

This investigation necessarily involves operations belonging to the higher branches of algebra and geometry; but this is not to be wondered at, when physical science has reached such a degree of development as to exhibit many of the laws of its phenomena.

Before proceeding with the strict investigation, it may be convenient to take a general review of the modifications which light undergoes in its transit through the instrument; as by that proceeding we shall be better prepared for seizing the full import of the analytic results. Let, then, ABCD represent the prime section of

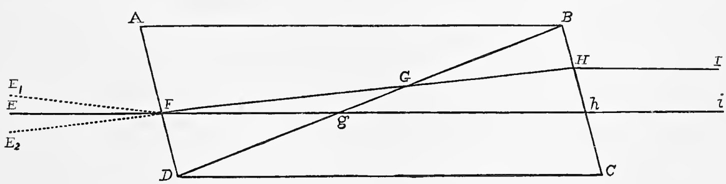


Fig. 1.

the eye-piece, BD the thin film of balsam inserted between the halves, and EF a ray of light incident on the surface AD: that ray will be refracted in two pencils, FH that submitted to the ordinary, F*h* that to the extraordinary, law. Were the rhomb entire these rays would again suffer refraction at the surface BC, and would emerge in directions HI, *hi* parallel to the incident ray:

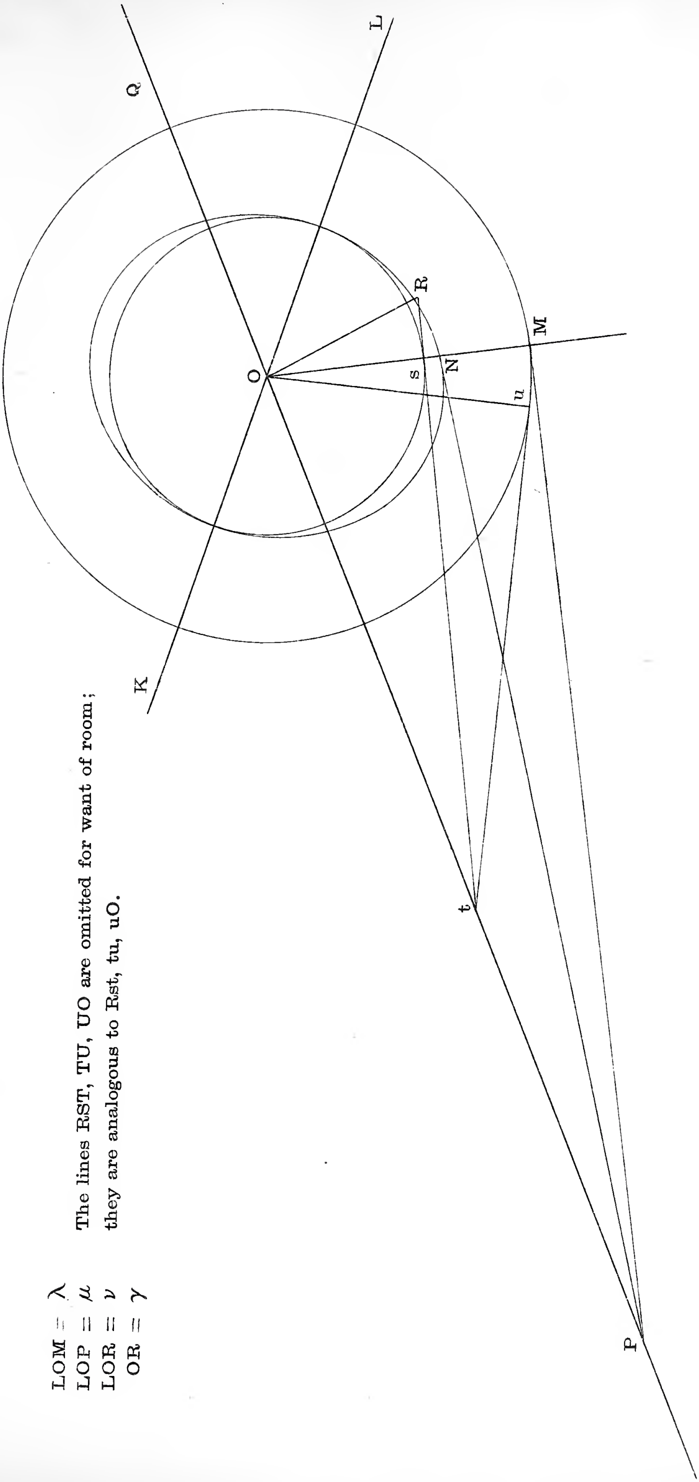
the same thing would happen were the surfaces BD in optical contact, that is, were they united by a substance having its index of refraction greater than or equal to the greater of the two indices for calcareous spar. But the index for Canada Balsam is less than that for carbonate of lime, and on this account the rays may not proceed uninfluenced.

If, indeed, the ray FG fall very obliquely on the surface of the varnish it may be totally reflected, no portion of it passing into the second wedge DBC. So it may also happen with the ray Fg; but as the two rays fall with different obliquities on the varnish, their limits of total reflection are different, and between these, the extraordinary light alone will find a passage.

The ray E_1F falls at such an angle that the ordinary pencil would barely suffer total reflection, while the extraordinary pencil would not. Any ray incident between the directions AF and E_1F would transmit both its pencils through the whole instrument. The ray E_2F, on the other hand, is so placed that both of its pencils suffer total reflection; and, hence, all rays within the angle E_1FE_2 will transmit to the eye only that portion which has experienced the extraordinary refraction, while no ray incident in the angle E_2FD will send any light through.

Such is the true action of the polarising eye-piece: it does not depend, as has been thought, on the separation of the images, for in truth there is never more than one image formed, and the virtual place of that image is not affected by the film of balsam. The perfection of its action depends on the magnitude of the angle E_1FE_2, which magnitude regulates the extent of the field of view; and on the transmitted light passing without being at all deflected in its path. For the attainment of the latter object, the surfaces AD, BC must be so placed that a ray of extraordinary light, passing in the interior parallel to the sides AB, may not suffer refraction in escaping at either surface. By this arrangement the light proceeds from the object to the eye, so that the first and last portions of its path are not only parallel to each other, but actually in one straight line. If this adjustment be not effected, there is created a parallax similar to that occasioned by the transmission of light obliquely through a thick plate of glass: that parallax affecting the apparent positions of near, but not those of distant, objects.

Fig 2.



The lines RST, TU, UO are omitted for want of room; they are analogous to Rst, tu, uO.

LOM = λ
LOP = μ
LOR = ν
OR = γ

The removal of this parallax is not altogether a matter of necessity, it is one rather of convenience, for by turning on the ends of the containing box circles parallel to each other, but on different axes, the inconvenience of the parallax would be entirely removed — the adjustment, however, of these axes would be troublesome.

The tendency of Iceland Spar to split in planes parallel to the faces of the primitive form renders almost unavoidable the employment of rhombs whose lengths are parallel to the arêtes of that form, economy in the amount of material being nearly as important as a maximum extent of field.

Regarding, then, the positions of the lines AB as determined by the cleavage, and those of AD by the condition of rectilineal transmission, there remains only to be determined the inclination of the plate DB of balsam. This inclination may be determined by attending to one or other of two conditions. Either we may so place this plate as to give the greatest angular field of view; or we may so fix it that the verges of that field are equally inclined to the direction AB: practically the latter consideration is the more important. It will, then, be proper, before attempting the enquiry into the best possible form of the instrument, having regard neither to the economy of the material nor to the introduction of parallax, first to determine the form which it ought to have when influenced by these restrictions.

The first thing to be determined is the angle ADC, which the diagonal AD of the end of the rhomb makes with the arête of the primitive form. Adopting the results of the elaborate investigations of M. Malus, let (fig. 2) the whole crystal be imagined to occupy the point O. Suppose that KOL is the direction of the axis of crystallisation, and ON that of the arête of the primitive form, and also of that portion of the ray which is interior to the crystal. Describe from O, as a centre, a sphere with the radius OM = unit, to represent the progress of a luminous pulse in air, and the interior ellipsoïde with its semi-axes ·604 and ·673 to represent the luminous pulse in the interior of calcareous spar.

In order to place the refracting surface OP in such a position that the pencil of extraordinary light may not be bent, we must apply tangent planes at the points M and N, and continue these

planes until they meet in the line P; the plane passing through this line P and the point O is parallel to the required refracting surface. For the determination then of the angle POM, which is supplementary to ADC of fig. 1, we only require the operations of ordinary trigonometry. Taking the inclination of the faces of calcareous spar at 105°..05′, as determined by the observations of Wollaston and Malus, we find the angle LOM, which the axis makes with the arête, to be 63°..44′..46″, and not as Malus has it, 66°..44′..46″.

$$\begin{aligned} \text{Log cot } 52^\circ..32'..30'' &= 9\cdot884\ \ 3264 \\ \text{Log } \sqrt{3} &= \ \ \cdot238\ \ 5606 \\ \hline \text{Log cos } 63^\circ..44'..45''\tfrac{41}{43} &= 9\cdot645\ \ 7658 \end{aligned}$$

This error of three degrees committed by M. Malus seems to have run throughout his work, and thus throws considerable uncertainty on his determination of the refractive indices.

Denoting this angle LOM by λ, and the semi-axes ·604, ·673 by α, β, the equation of the plane MP is

$$x\,x_M + y\,y_M = 1\,,$$

or

$$x \cos \lambda + y \sin \lambda = 1 \quad . \quad . \quad . \quad . \quad . \quad (\text{MP})\,;$$

while that of the plane NP is

$$\frac{x x_N}{\alpha^2} + \frac{y y_N}{\beta^2} = 1\,,$$

or since

$$x_N = \frac{\alpha\beta \cos \lambda}{\sqrt{(\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2)}}\,;\ y_N = \frac{\alpha\beta \sin \lambda}{\sqrt{(\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2)}}\,,$$

$$\left\{\frac{x \cos \lambda}{\alpha^2} + \frac{y \sin \lambda}{\beta^2}\right\} \frac{\alpha\beta}{\sqrt{(\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2)}} = 1\,;$$

that is,

$$\frac{x \cos \lambda}{\alpha^2} + \frac{y \sin \lambda}{\beta^2} = \frac{\sqrt{(\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2)}}{\alpha\beta} \quad . \quad . \quad (\text{NP}).$$

Hence, as the line P is common to both of these planes, we obtain by elimination

$$y_P \sin \lambda = \beta \frac{\beta - \alpha \sqrt{(\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2)}}{\beta^2 - \alpha^2}$$

$$x_P \cos \lambda = \alpha \frac{-\alpha + \beta \sqrt{(\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2)}}{\beta^2 - \alpha^2}$$

from which equations we deduce the value of the tangent of the angle LOP,

$$\tan \mathrm{LOP} = -\frac{\beta}{\alpha} \cot \lambda \frac{\beta - \alpha \sqrt{\{\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2\}}}{\alpha - \beta \sqrt{\{\alpha^2 \sin \lambda^2 + \beta^2 \cos \lambda^2\}}},$$

from which we obtain the numerical value

$$\text{supp. LOP} = 41^\circ \,..\, 14' \,..\, 13\tfrac{1}{2}'' \text{ (say } 14''\text{)};$$

whence, by adding the angle LOM, we obtain

$$\mathrm{MOQ} = 104^\circ \,..\, 58' \,..\, 59\tfrac{1}{2}'' \quad \text{Say}$$

$$\text{ADC (fig. 1)} = 104 \,..\, 59\,.$$

Now, the inclination of the arête to the face of the primitive rhomb is 109° .. 08′, so that, in forming an eye-piece, the ends must be inclined 4° .. 09′ less than the natural face is.

This result is opposed to the instructions given by Mr Nicol in his first description of the instrument: he directs that the obliquity be increased, whereas we have found that it must be diminished 4°; and, indeed, on inspection of those eye-pieces which have been made agreeably to his instructions, it will be found that the ray of light proceeding in the interior of the crystal parallel to the arête suffers refraction at each surface, and that the ray which does not suffer refraction passes in a direction intermediate between the line of the arête and the diagonal joining the two obtuse corners.

Having now determined this element of the artificial rhomb, there remains for me the solution of another question. It is this: To place the plate of balsam so that the extent of field may be placed equally on each side of the line of sight. For this, a new element enters into the investigation; the refractive power of the balsam.

Let OR represent the direction of the plate of cement, and measure off OR to represent the velocity of light in that medium; the limiting directions of the two pencils will be thus obtained.

First, for the ordinary ray; describe a sphere round O with the radius α, and from R apply to that sphere the tangent plane Rs, meeting the surface OP in the line t; then from that line apply a plane touching the sphere pertaining to the air in the point u, Ou is the direction of that external ray, of which the ordinary pencil

just suffers total reflection at the surface of the balsam; this is one of the boundaries of the field of view.

Again, from the same point R apply the plane RST touching the spheroïde in S, and cutting the surface OP in T; the tangent plane TU will give the direction of OU the limiting extraordinary ray.

The question is to place OR, so that the angle UOu may be bisected by the line OM.

For the analytic solution of this problem we have only to go into detail with the investigation for extraordinary light; since the insertion of $\beta = \alpha$ in any formula for that species of light will give the corresponding formula for ordinary light.

Denote the angle LOP by μ, the required angle LOR by ν, and the velocity of light in Canada Balsam by γ: then are the co-ordinates of the point R

$$x_{\mathrm{R}} = \gamma \cos \nu\,; \quad y_{\mathrm{R}} = \gamma \sin \nu\,.$$

But the equation of a plane passing through R, and touching the spheroïde, is

$$\left.\begin{array}{l} x\{\beta^2 x_{\mathrm{R}} \pm y_{\mathrm{R}} \sqrt{(\alpha^2 y_{\mathrm{R}}^2 + \beta^2 x_{\mathrm{R}}^2 - \alpha^2\beta^2)}\} \\ + y\{\alpha^2 y_{\mathrm{R}} \mp x_{\mathrm{R}} \sqrt{(\alpha^2 y_{\mathrm{R}}^2 + \beta^2 x_{\mathrm{R}}^2 - \alpha^2\beta^2)}\} \end{array}\right\} = \alpha^2 y_{\mathrm{R}}^2 + \beta^2 x_{\mathrm{R}}^2\,,$$

or

$$\left.\begin{array}{l} x\left\{\beta^2 \cos\nu \pm \gamma \sin\nu \sqrt{\left(\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2 - \dfrac{\alpha^2\beta^2}{\gamma^2}\right)}\right\} \\ + y\left\{\alpha^2 \sin\nu \mp \gamma \cos\nu \sqrt{\left(\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2 - \dfrac{\alpha^2\beta^2}{\gamma^2}\right)}\right\} \end{array}\right\} = \gamma(\alpha^2 \sin \nu^2 + \beta^2 \cos \nu^2)\,.$$

From the inspection of the figure it is clear that

$$x_{\mathrm{T}} = \sec \mathrm{POU} \,.\, \cos \mu$$
$$y_{\mathrm{T}} = \sec \mathrm{POU} \,.\, \sin \mu$$

which values inserted in the above equation of the tangent plane give, after reduction, and putting $\epsilon^2 = \beta^2 - \alpha^2$,

$$\cos \mathrm{POU} = \frac{\epsilon^2 \cos\mu \cos\nu + \alpha^2 \cos(\mu - \nu) \mp \gamma \sin(\mu - \nu) \sqrt{\left(\epsilon^2 \cos\nu^2 - \dfrac{\alpha^2}{\gamma^2}(\beta^2 - \gamma^2)\right)}}{\gamma(\alpha^2 + \epsilon^2 \cos \nu^2)}\,.$$

The supposition $\beta = \alpha$, $\epsilon = 0$ in this formula will give the value of the cosine of the limiting angle for ordinary light: thus

$$\cos \mathrm{PO}u = \frac{a \cos(\mu - \nu) \mp \sqrt{\gamma^2 - a^2} \sin(\mu - \nu)}{a\gamma}.$$

The object is to find a value of ν which would give

$$\mathrm{POU} + \mathrm{PO}u = 2(\mu - \lambda),$$

which would be accomplished by resolving the equation

$$\tan(\mu - \lambda) = \frac{\sin \mathrm{POU} + \sin \mathrm{PO}u}{\cos \mathrm{POU} + \cos \mathrm{PO}u};$$

but the labour attending the exhibition and direct resolution of this equation would be enormous. I have, therefore, preferred the method of approximation.

In making this approximation we derive a guide from the last term of the numerator of cosPOU; which becomes imaginary when $\epsilon^2 \cos \nu^2$ is less than the known quantity $\frac{a^2}{\gamma^2}(\beta^2 - \gamma^2)$. This limit, which gives $(\nu) = 57° \,..\, 55'$, corresponds to the intersection of the ellipse with a circle described with the radius OR.

I, therefore, assumed three values of ν, or rather of $\mu - \nu$, and computed thence the corresponding values of POU, POu, and of the error $\frac{1}{2}(\mathrm{POU} + \mathrm{PO}u) - (\mu - \lambda)$, as under

$\mu - \nu$	ν	POU	POu	Error
85°	53°..45'..46"	80°..04'..56"	40°..01'..32"	−14°..57'..46"
90	48..45..46	83..00..21	50..35..13	− 8..13..13
95	43..45..46	86..48..08	60..03..04	− 1..35..24

where the extent of field (POU − POu) is observed to decrease, the greatest possible extent of field being obtained when ν has the limiting value: but then this convenience of a large field is counteracted by having it unsymmetrically placed in reference to the line of sight; as well as by the necessity of using a very long rhomb which would give another limit to the extent of view.

Computing, by the ordinary method, from these three results, that value of ν which may give no error, we find $\nu = 42° \,..\, 33' \,..\, 00''$; but this is only an approximation. Computing from it the value of the error, we find

$$\mathrm{POU} = 87° \,..\, 52' \,..\, 39''; \quad \mathrm{PO}u = 62° \,..\, 14' \,..\, 39'',$$

giving an error of $+2' \,..\, 39''$, from which we infer

$$\left.\begin{array}{r}\{\mu-\nu\}=96^\circ\,..\,10'\,..\,48'' \\ \{\nu\}=42\,..\,34\,..\,58\end{array}\right\}\text{field}=25^\circ\,..\,40'\,.$$

This value of POR, $96^\circ\,..\,11'$, differs by six degrees from the determination of Mr Nicol; but as the surface according to that gentleman is inclined by seven degrees to the position assigned by theory, it follows that the value of ν, or the position of the plate of balsam in reference to the axis of the crystal, is nearly the same in his instrument, as by the above determination.

If, indeed, an eye-piece, constructed according to the directions of the inventor, be placed so that the light from any object pass in the interior parallel to the length of the rhomb, that object will be found considerably nearer the limit of the ordinary than that of the extraordinary light.

The above angles are sufficient to guide the operator in the construction of the eye-piece. But it is to be remarked that the advantages sought in this construction do not balance the disadvantage of a diminished field; and that Mr Nicol's dimensions are preferable.

Having now completed the investigation of the best form for a rhomb whose faces are obtained by cleavage, I shall proceed to investigate the absolutely best form independent of that consideration.

In strictness, this investigation ought to be founded on the above values of POU, POu. It ought to include the solution of the equation

$$\mathrm{POU}+\mathrm{PO}u=2(\mu-\lambda)\,.$$

The root of that equation determined, the value of POU − POu should be thence deduced. Then the maximum value of that field ought to be sought, μ and λ being the primary variables.

Or if the condition of non-refraction of the line of sight be included, μ becomes a function of λ, and hence the differentiation becomes monome. This investigation however is, on account of its complexity, almost impracticable: for it I shall substitute another.

Instead of seeking the maximum separation of the limiting rays exterior to the rhomb, I shall seek for that position of the plate of balsam which gives the greatest internal divergence, which depends

simply on α, β, γ; after it is determined it will then be proper to enquire, what position of the ends of the rhomb will give symmetry in the placing of the field of view.

We must, then, determine the position of OR so that the angle SOs may be a maximum. Now, it is obvious that the angle ROs is constant, having for its cosine the ratio $\frac{\alpha}{\gamma}$: and thus we have to seek only for that position of OR which gives ROS a minimum or a maximum.

ROS will, in the particular state of matters, be a minimum, actually zero, when OR is a semi-diameter of the ellipse, that is, when $(\nu) = 57° \,..\, 55'$; but if ROS be greater than ROs, SOs will be the excess ROS − ROs, and we must then seek for ROS a maximum, not a minimum.

The equation of a plane touching the ellipse of S is

$$\frac{x_S x}{\alpha^2} + \frac{y_S y}{\beta^2} = 1 \,,$$

and since that plane must pass through R

$$\frac{x_S x_R}{\alpha^2} + \frac{y_S y_R}{\beta^2} = 1 \,,$$

from which equation, and the equation of the spheroïde, we may determine x_S, y_S, the ordinates of the point of contact,

$$x_S = \alpha^2 \frac{\beta^2 x_R \mp y_R \sqrt{(\alpha^2 y_R^2 + \beta^2 x_R^2 - \alpha^2\beta^2)}}{\alpha^2 y_R^2 + \beta^2 x_R^2} \,,$$

$$y_S = \beta^2 \frac{\alpha^2 y_R \pm x_R \sqrt{(\alpha^2 y_R^2 + \beta^2 x_R^2 - \alpha^2\beta^2)},}{\alpha^2 y_R^2 + \beta^2 x_R^2}$$

in which, substituting for x_R, y_R their values, we obtain

$$x_S = \frac{\alpha^2}{\gamma} \; \frac{\beta^2 \cos\nu \mp \sin\nu \sqrt{\{\gamma^2(\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2) - \alpha^2\beta^2\}}}{\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2} \,,$$

$$y_S = \frac{\beta^2}{\gamma} \; \frac{\alpha^2 \sin\nu \pm \cos\nu \sqrt{\{\gamma^2(\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2) - \alpha^2\beta^2\}}}{\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2} \,;$$

whence

$$\tan \mathrm{LOS} = \frac{\beta^2}{\alpha^2} \; \frac{\alpha^2 \sin\nu \pm \cos\nu \sqrt{\{\gamma^2(\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2) - \alpha^2\beta^2\}}}{\beta^2 \cos\nu \mp \sin\nu \sqrt{\{\gamma^2(\alpha^2 \sin\nu^2 + \beta^2 \cos\nu^2) - \alpha^2\beta^2\}}} .$$

Now, ROS is the difference between LOS and ν, so that when ROS is minimum or maximum $\delta\text{ROS} = \delta\nu$; that is, since $\delta\text{ROS}(\sec\text{ROS})^2 = \delta\tan\text{ROS}$

$$\delta\nu(\sec\text{ROS})^2 = \delta\,.\,\tan\text{ROS}\,.$$

Putting

$$\sqrt{\left(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2 - \frac{\alpha^2\beta^2}{\gamma^2}\right)} = \text{N}\,,$$

$$\tan\text{LOS} = \frac{\alpha^2\beta^2\sin\nu \pm \beta^2\gamma\text{N}\cos\nu}{\alpha^2\beta^2\cos\nu \mp \alpha^2\gamma\text{N}\sin\nu}\,;$$

whence

$$(\sec\text{ROS})^2 = \frac{\alpha^4\beta^4 \pm 2\alpha^2\beta^2\epsilon^2\,.\,\gamma\text{N}\,.\,\sin\nu\cos\nu + (\alpha^4\sin\nu^2 + \beta^4\cos\nu^2)\gamma^2\text{N}^2}{(\alpha^2\beta^2 \mp \alpha^2\gamma\text{N}\sin\nu)^2}\,;$$

and also

$$\frac{\delta\tan\text{ROS}}{\delta\nu} = \frac{\alpha^4\beta^4 + \alpha^2\beta^2\gamma^2\text{N}^2 \pm \alpha^2\beta^2\gamma(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2)\dfrac{\delta\text{N}}{\delta\nu}}{(\alpha^2\beta^2 \mp \alpha^2\gamma\text{N}\sin\nu)^2}\,;$$

so that the value of ν will be determined by equating the numerators of these two fractions. Thus

$$(\alpha^4\sin\nu^2 - \alpha^2\beta^2 + \beta^4\cos\nu^2)\gamma^2\text{N}^2 \pm 2\alpha^2\beta^2\epsilon^2\gamma\text{N}\sin\nu\cos\nu = \pm\alpha^2\beta^2\gamma(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2)\frac{\delta\text{N}}{\delta\nu}\,,$$

or

$$(\beta^2\cos\nu^2 - \alpha^2\sin\nu^2)\epsilon^2\gamma^2\text{N}^2 \pm 2\alpha^2\beta^2\epsilon^2\gamma\text{N}\sin\nu\cos\nu = \mp\frac{\alpha^2\beta^2\gamma\epsilon^2(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2)\sin\nu\cos\nu}{\text{N}}$$

whence, after repeated simplifications,

$$(-\alpha^4\sin\nu^4 + \beta^4\cos\nu^4)\gamma^2 + \alpha^2\beta^2(\alpha^2\sin\nu^2 - \beta^2\cos\nu^2)$$

$$\pm 2\alpha^2\beta^2\gamma\sqrt{\left(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2 - \frac{\alpha^2\beta^2}{\gamma^2}\right)}\cos\nu\sin\nu$$

$$\pm\frac{\alpha^2\beta^2\gamma(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2)\cos\nu\sin\nu}{\sqrt{\left(\alpha^2\sin\nu^2 + \beta^2\cos\nu^2 - \dfrac{\alpha^2\beta^2}{\gamma^2}\right)}} = 0$$

$$(-\alpha^2\sin\nu^2 + \beta^2\cos\nu^2)\gamma^2\left\{\alpha^2\sin\nu^2 + \beta^2\cos\nu^2 - \frac{\alpha^2\beta^2}{\gamma^2}\right\}^{\frac{3}{2}}$$

$$= \mp 2\alpha^2\beta^2\gamma\cos\nu\sin\nu\left\{\alpha^2\sin\nu^2 + \beta^2\cos\nu^2 - \frac{\alpha^2\beta^2}{\gamma^2}\right\}$$

$$\mp\;\alpha^2\beta^2\gamma\cos\nu\sin\nu\,\{\alpha^2\sin\nu^2 + \beta^2\cos\nu^2\}$$

$$= \mp\;\alpha^2\beta^2\gamma\cos\nu\sin\nu\left\{3\alpha^2\sin\nu^2 + 3\beta^2\cos\nu^2 - 2\frac{\alpha^2\beta^2}{\gamma^2}\right\}$$

whence squaring

$$(-\alpha^2 \sin \nu^2 + \beta^2 \cos \nu^2)^2\gamma^2\left(\alpha^2 \sin \nu^2 + \beta^2 \cos \nu^2 - \frac{\alpha^2\beta^2}{\gamma^2}\right)^3$$

$$= \alpha^4\beta^4 \cos \nu^2 \sin \nu^2\left(3\alpha^2 \sin \nu^2 + 3\beta^2 \cos \nu^2 - 2\frac{\alpha^2\beta^2}{\gamma^2}\right)^2$$

which is an equation of the fifth order, $\sin \nu^2$ being the unknown quantity.

For the convenience of development put

$$\alpha^2 \sin \nu^2 = \mathrm{A}\ ;\ \beta^2 \cos \nu^2 = \mathrm{B}\ ;\ \frac{\alpha^2\beta^2}{\gamma^2} = \mathrm{C}\ ;$$

then the equation becomes

$$(-\mathrm{A}+\mathrm{B})^2\gamma^2(\mathrm{A}+\mathrm{B}-\mathrm{C})^3 = \mathrm{AB}(3\mathrm{A}+3\mathrm{B}-2\mathrm{C})^2\alpha^2\beta^2\,,$$

or

$$\{\mathrm{A}^5 + \mathrm{A}^4\mathrm{B} - 2\mathrm{A}^3\mathrm{B}^2 - 2\mathrm{A}^2\mathrm{B}^3 + \mathrm{AB}^4 + \mathrm{B}^5\} + \mathrm{C}\{-3\mathrm{A}^4 - 9\mathrm{A}^3\mathrm{B} - 12\mathrm{A}^2\mathrm{B}^2 - 9\mathrm{AB}^3 - 3\mathrm{B}^4\}$$
$$+ \mathrm{C}^2\{3\mathrm{A}^3 + 9\mathrm{A}^2\mathrm{B} + 9\mathrm{AB}^2 + 3\mathrm{B}^3\} + \mathrm{C}^3\{-\mathrm{A}^2 - 2\mathrm{AB} - \mathrm{B}^2\} = 0\,.$$

Or, again,

$$(\mathrm{A}+\mathrm{B})^3(\mathrm{A}-\mathrm{B})^2 - 3\mathrm{C}(\mathrm{A}+\mathrm{B})^2(\mathrm{A}^2+\mathrm{AB}+\mathrm{B}^2) + 3\mathrm{C}^2(\mathrm{A}+\mathrm{B})^3 - \mathrm{C}^3(\mathrm{A}+\mathrm{B})^2 = 0\,,$$

hence as two of the solutions of the equation we have $\mathrm{A}+\mathrm{B}=0$, the roots of which are clearly imaginary. The remaining solutions belong to the equation

$$(\mathrm{A}+\mathrm{B})(\mathrm{A}-\mathrm{B})^2 - 3\mathrm{C}(\mathrm{A}^2+\mathrm{AB}+\mathrm{B}^2) + 3\mathrm{C}^2(\mathrm{A}+\mathrm{B}) - \mathrm{C}^3 = 0\,,$$

which is only of the third order in reference to the unknown quantity $\sin \nu^2$. This equation may be put under the form

$$\sin \nu^6\epsilon^2(2\beta^2-\epsilon^2)^2 + \sin \nu^4\frac{\beta^2}{\gamma^2}\{3\alpha^2(\beta^4-\beta^2\epsilon^2+\epsilon^4) - \gamma^2(4\beta^4-\epsilon^4)\}$$

$$+ \sin \nu^2\frac{\beta^4}{\gamma^4}\{3\alpha^4\epsilon^2 - 3\gamma^2(\beta^4-\epsilon^4) + \gamma^4(4\beta^2-\epsilon^2)\} - \frac{\beta^6}{\gamma^6}(\gamma^2-\alpha^2)^3 = 0\,.$$

Put here $\sin \nu^2 = x\dfrac{\beta^2}{\gamma^2}$, and we have

$$x^3\,.\,\epsilon^2(2\beta^2-\epsilon^2)^2 + x^2\{3\alpha^2(\beta^4-\beta^2\epsilon^2+\epsilon^4) - \gamma^2(4\beta^4-\epsilon^4)\}$$

$$+ x\{3\alpha^4\epsilon^2 - 3\alpha^2\gamma^2(\beta^2+\epsilon^2) + \gamma^4(4\beta^2-\epsilon^2)\} - (\gamma^2-\alpha^2)^3 = 0\,,$$

which becomes on substituting the numerical values for α^2, β^2, ϵ^2, γ^2,

$$\left\{\begin{array}{lll} \epsilon^2 = \cdot 088\ 113\,; & \alpha^2 = \cdot 364\ 816\,; & \beta^2 = \ \ \cdot 452\ 929 \\ \gamma^2 = \cdot 427\ 716\,; & \gamma^2 - \alpha^2 = \cdot 062\ 900\,; & \beta^2 + \epsilon^2 = \ \ \cdot 541\ 042 \\ 2\beta^2 + \epsilon^2 = \cdot 993\ 971\,; & 2\beta^2 - \epsilon^2 = \cdot 817\ 745\,; & 4\beta^2 - \epsilon^2 = 1 \cdot 723\ 603 \end{array}\right\}$$

$$0 \cdot 058\ 9218 x^3 - 0 \cdot 158\ 3148 x^2 + 0 \cdot 097\ 2308 x - 0 \cdot 000\ 248858 = 0\,.$$

This equation has three roots, only one of which is consistent with other conditions not involved in the algebraic expression of the problem: that root is

$$x = \cdot 0025702\,,$$

whence

$$\nu = 2^\circ \ldots 59' \ldots 25''\,,$$

a result which gives the maximum value of ROS, and therefore the minimum of SO*s*; or the maximum of − SO*s*.

The value of ROS deduced from the above ν is 24° .. 40′ .. 23″, while the constant value of RO*s* is 22° .. 32′ .. 59″; thus leaving for SO*s* only 2° .. 07′ .. 24″ as the maximum when O*s* falls between OS and the axis. This leaves so small a difference between the interior rays which experience total reflection at the surface of the balsam, that it is needless to pursue the investigation farther. It may be at once held as demonstrated that the best position for the plane of cement is beyond the limit which gives a coincidence to the two interior rays OS, O*s*; and that we must seek for the best possible position beyond that limit.

The maximum value of RO*s* − ROS must, since RO*s* is constant, accompany the minimum value of ROS, which minimum value, since both angles must always lie on the same side of OR, is zero. We might, therefore, be led to suppose that the best value of LOR is $(\nu) = 57^\circ \ldots 55'$. But in reality, any value of LOR between 57° .. 55′ and its supplement 122° .. 05′ is accompanied by this circumstance, that no pencil of extraordinary light is intercepted by the balsam. Hence in considering the values of ν between these limits, we have only to examine the condition of total reflection of the ordinary ray; this examination is a matter of comparative facility.

Having thus found a wide range of angles accompanied by no interruption of the extraordinary ray, we might enquire what particular angle would give the most extensive field of view; but

in reality, all positions of the plane OR give the same value, 22°..33′, to the angle RO*s*, so that the position of OR between these limits is indeterminable by this condition.

Another and remarkable condition may, however, be proposed: viz., so to place the external surface, that no ray of ordinary light entering the eye-piece may pass through it; while at the same time not a single extraordinary ray is intercepted. The construction of an eye-piece to satisfy these conditions would seem to give every requisite desirable in such an instrument.

Let AB represent the position of the plate of

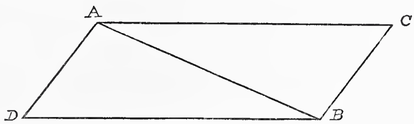


Fig. 3.

balsam, anywhere intermediate between 57°..55′ and 102°..05′ from the axis. Make ABD = 22°..33′; any ray of ordinary light passing in the interior between AB and DB would suffer total reflection; no ray beyond DB would be intercepted. We wish, then, that no ordinary ray entering the substance may make with the line AB an angle greater than 22°..33′: in other words, a ray of light BD passing in the interior ought to suffer total reflection at the outer surface. The angle ADB, then, ought to have for its cosine the ratio α; whence

$$\begin{aligned} ADB &= 52°..50'..35'' \\ ABD &= \underline{22\ ..32..59} \\ BAD &= 104\ ..38..26 \end{aligned}$$

Assuming AC as the limit of the rhomb, and making that coincide with the direction of the arête of the primary form, the whole instrument is defined. With this eye-piece, as a matter of course, there are no separating bands perceived.

In all of these enquiries the object has been to exclude the ordinary and transmit the extraordinary pencil. But the converse question may also be proposed.

At a glance it is seen that no combination similar to that which we have been considering can supply the requisite conditions. We

must place the calcareous spar between two wedges of a medium having a greater action on light.

If a plate of spar be placed between two wedges of glass, having its index of refraction just equal to the index of calcareous spar for ordinary light, no ordinary ray would be intercepted; and there would remain the question—so to form these wedges as to exclude the extraordinary pencil, as also to determine the manner in which the slice of spar should be cut from the crystal.

Supposing a glass obtained with the refractive power $\frac{1}{\alpha} = 1{\cdot}655$; it is obvious at once that the best direction for the slice of calcareous spar is across the axis of crystallisation. The angle at which the extraordinary ray interior to the glass would suffer total reflection would have $\frac{\alpha}{\beta}$ for its cosine; hence, that angle would be $26^\circ\,..\,10'\,..\,19''$

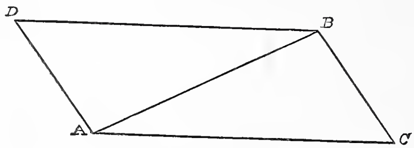


Fig. 4.

Let, then, AB represent a plate of Iceland Spar cut at right angles to the axis: ABD, ABC, two wedges of glass ind. ref. $= 1{\cdot}655$. Make ABD $= 26^\circ\,..\,10'\,..\,19''$, and a ray of light between AB and DB would send through only the ordinary pencil; beyond DB both would pass. Make, again, the angle BDA such that its cosine is α, that is, make it $52^\circ\,..\,50'\,..\,35''$, and, of course, BAD $= 100^\circ\,..\,59'\,..\,06''$; and then, while no ordinary ray is intercepted, no extraordinary one is suffered to pass.

When the refractive power of the glass employed is not the inverse of α, the computations become more intricate; but they resemble so closely those of the first part of this paper that it is needless here to go over them.

The importance of the eye-piece as an instrument for experimental research, entitles it to a strict and minute analysis, that we may call into action the full development of its powers, and thus make sure of losing none of the benefits which it promises to confer.

30th January 1837.

Note on Dr Sang's Paper. By Prof. Tait.

(Read November 23, 1891.)

At the very urgent request of the late Dr Sang, who regarded the above paper as one of his chief contributions to science, I brought before the Council of the Society the question of its publication. From the Minute-Book of the Ordinary Meetings, I find that it was read on the 20th February 1837, though it is not mentioned in the published *Proceedings* of that date. On 21st July 1891 the Council finally resolved that the paper should be printed in the *Proceedings* "if otherwise found desirable." The reasons in favour of printing it seem to outweigh those which may, readily enough, be raised against such a course.

The subject is one with which, except of course in its elements, I have long ceased to be familiar. But, from the imperfect examination which I have found leisure to make, I have come to the following conclusions.

The paper contains a very important suggestion which (one would have thought) should have been forthwith published, whatever judgment might be passed on the rest of the work:—viz., the proposal to construct the polariser of two glass prisms, separated by a thin layer, only, of Iceland spar. In view of the scarcity of this precious substance, such a suggestion was obviously of great value.

I am not sufficiently acquainted with the early history of the Nicol prism to be able to pronounce on the question of Dr Sang's claim to priority in the explanation of its action:—but he told me that he believed himself to have been the first to *demonstrate* that the separation effected was due to the total reflection of the ordinary ray. And it is quite certain that, long subsequent to 1837, various very singular attempts at explanation have been given in print. The inventor, himself, seems to have thought that the effect of his instrument was merely to "increase the divergency" of the two rays.

The numerical error which Dr Sang has pointed out in Malus' work seems to have been a slip of the pen only, as the minutes and seconds of the angle in question are correctly given. He supplies no reference to the passage, but I find it in the list of calculated angles at p. 125 of the *Théorie de la Double Réfraction.* It cannot be a mere misprint, because the supplement is given along with the angle,

and is affected by the corresponding error. But I do not think that Dr Sang's further remark is justified, as Malus not only gives the correct expression for the cosine of the angle in question, but seems to have employed in his subsequent calculations the inclination of the axis to a *face*, not to an *edge*, of the crystal :—and he gives the accurate numerical value of this quantity, as deduced from Wollaston's measure of the angle between two faces.

There is an altogether unnecessarily tedious piece of analysis in Dr Sang's investigation of the limits within which the prism works:—and it is so even although he shortens it by the introduction of the terribly significant clause "after repeated simplifications." I will give below what I consider to be a natural and obvious mode of dealing with the question (one which, besides, leads to some elegant results) :—but I have reproduced Dr Sang's manuscript *as it was read*, for the circumstances of the present publication seem to require literal accuracy. Dr Knott has kindly verified for me the agreement of my final equation with that of Dr Sang.

In p. 331, above, it is clear that, since S is a point on the spheroid, we may put

$$x_S = \alpha \cos \phi \,, \quad y_S = \beta \sin \phi \,.$$

But we have (p. 328)

$$x_R = \gamma \cos \nu \,, \quad y_R = \gamma \sin \nu \,.$$

Hence the general relation between R and S, *i.e.*, between ϕ and ν, is

$$\frac{\cos \phi \cos \nu}{\alpha} + \frac{\sin \phi \sin \nu}{\beta} = \frac{1}{\gamma} \,.$$

Also, since the angle ROS is to be a maximum,

$$\frac{d}{d\nu}\left(\tan^{-1}\left(\frac{\beta}{\alpha}\tan\phi\right) - \nu\right) = 0 \,.$$

Differentiating the first equation, and eliminating $d\phi/d\nu$ between the two, we get at once the remarkably simple relation

$$(\tan \phi)^3 = -\frac{\alpha}{\beta}\tan \nu \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

But we may put the first into the form

$$\frac{\cos \nu}{\alpha} + \frac{\sin \nu}{\beta}\tan \phi = \frac{1}{\gamma}\sec \phi \,,$$

or

$$\frac{(\cos \nu)^2}{\alpha^2} - \frac{1}{\gamma^2} + \frac{2\cos \nu \sin \nu}{\alpha\beta}\tan \phi + \left(\frac{(\sin \nu)^2}{\beta^2} - \frac{1}{\gamma^2}\right)(\tan \phi)^2 = 0 \quad . \quad (2).$$

The elimination of $\tan\phi$ between (1) and (2) is easily effected by multiplying (2) twice over by $\tan\phi$, using (1) after each operation. We thus avoid the radicals which make Dr Sang's work so complicated, and we have only to eliminate $\tan\phi$ and $(\tan\phi)^2$ among three equations of the first degree. The resulting equation is of the fourth degree in $(\sin\nu)^2$, but it contains the irrelevant factor

$$\frac{(\cos\nu)^2}{\alpha^2}+\frac{(\sin\nu)^2}{\beta^2}.$$

[Another method of effecting the elimination, while quite as simple as that just given, has the advantage of not introducing the irrelevant factor. Write for shortness

$$\frac{\cos\nu}{\alpha}=p\,,\quad \frac{\sin\nu}{\beta}=q\,,$$

and we have

$$p\cos\phi+q\sin\phi=\frac{1}{\gamma}\,,$$

$$p(\sin\phi)^3+q(\cos\phi)^3=0\,.$$

From the second of these, by the help of the first, we at once obtain

$$p\sin\phi+q\cos\phi=\frac{1}{\gamma}\cos\phi\sin\phi\,,$$

or

$$\frac{p}{\cos\phi}+\frac{q}{\sin\phi}=\frac{1}{\gamma}.$$

The following are immediate consequences:—obtained, respectively, by multiplying together the first and fourth of these equations, and by squaring and adding the first and third:—

$$p^2+q^2+\frac{pq}{\sin\phi\cos\phi}=\frac{1}{\gamma^2}\,,$$

$$p^2+q^2+4pq\sin\phi\cos\phi=\frac{1}{\gamma^2}\Big(1+(\sin\phi\cos\phi)^2\Big).$$

From these the final result may be written by inspection, in the form

$$p^2+q^2+\frac{4p^2q^2}{\dfrac{1}{\gamma^2}-p^2-q^2}=\frac{1}{\gamma^2}\left(1+\frac{p^2q^2}{\left(\dfrac{1}{\gamma^2}-p^2-q^2\right)^2}\right),$$

or

$$\left(p^2+q^2-\frac{1}{\gamma^2}\right)^3-4p^2q^2\left(p^2+q^2-\frac{1}{\gamma^2}\right)=\frac{p^2q^2}{\gamma^2}\,,$$

which is obviously of the third degree in $(\sin\nu)^2$.]

It is clear that there are other parts of Dr Sang's paper which might be greatly simplified by the use of an auxiliary angle; but it suffices to have shown the value of the method in the most complicated part of the investigation.

[*P.S.*—*Nov.* 23, 1891.—Mr R. T. Glazebrook has kindly given me a reference to *Comptes Rendus*, xcix. 538 (1884), where M. E. Bertrand has suggested the employment of glass prisms separated by a thin layer of Iceland spar.]

On the Extension of Brouncker's Method to the Comparison of several Magnitudes. By Edward Sang, LL.D.

(Read December 15, 1890.)

In the paper on this subject, printed in the twenty-sixth volume of the Society's *Transactions*, the general principles only of this extension were explained; since then the subject has lain aside. An accident has drawn attention to the use of this method for determining cube-roots, and particularly in regard to the duplication of the cube. The consideration of this matter has led to the observation of certain relations which deserve to be recorded.

Here we have to compare three quantities which are in continued geometrical progression. From the greatest of these we deduct multiples of the others to obtain a fourth magnitude or remainder less than the least of the preceding; leaving off now the greatest, we treat the remaining three quantities in the same way, and so proceed until the remainder become insignificant or, in the case of commensurables, become zero.

In the former explanation the three quantities were arranged in the order of decreasing magnitude, and the second was taken as often as possible from the first before the subtraction of the third was attempted, and the three quantities in hand remained arranged in the order of decreasing magnitude.

For the sake of illustration we may take the case of the cube-root of 2, in which case we have the three quantities $\sqrt[3]{4}$, $\sqrt[3]{2}$ and 1, to be compared. Expressing them numerically, we have

$$1.5874011 = A,$$
$$1.2599210 = B,$$
$$1.0000000 = C.$$

The second of these deducted *once* from the first leaves a remainder less than the third, therefore we write $A = 1.B + 0.C + D$, leaving $D = .3274801$. Treating B, C, D in the same way we find

B = 1.C + 0.D + E, leaving E = .2599210. Here, however, on comparing C, D, E, we find that D may be taken thrice from C, and we get C = 3.D + 0.E + F, leaving F = 175597; and thus the work proceeds, as shown in the accompanying scheme:—

$$
\begin{aligned}
1.5874011 = A &= 1.B + 0.C + D \\
1.2599210 = B &= 1.C + 0.D + E \\
1.0000000 = C &= 3.D + 0.E + F \\
.3274801 = D &= 1.E + 3.F + G \\
.2599210 = E &= 14.F + 0.G + H \\
175597 = F &= 1.G + 0.H + I \\
148800 = G &= 1.H + 0.I + K \\
140852 = H &= 5.I + 0.K + L \\
26797 = I &= 3.K + 0.L + M \\
7948 = K &= 1.L + 0.M + N \\
6867 = L &= 2.M + 0.N + O \\
2953 = M &= 2.N + 0.O + P \\
1081 = N &= 1.O + 0.P + Q \\
961 = O &= 1.P + 1.Q + R \\
791 = P &= 6.Q + 1.R + S \\
120 = Q &= 2.R + 1.S \\
50 &= R \\
21 &= S.
\end{aligned}
$$

In the work so carried on, there is no appearance of recurrence among the quotients, such as is seen when two quantities are compared for the purpose of finding the square-root. But here we have followed the purely arbitrary rule of making as many subtractions as possible of the second from the first of the three quantities. We might have written,

$$C = 2.D + 1.E + F$$

or

$$C = 1.D + 2.E + F,$$

or even

$$C = 0.D + 3.E + F.$$

In such case we should have a change in the sequence of the quotients, but any of these, if continued to exhaust the absolute numbers proposed, would necessarily result in reproducing those very numbers.

On using the first of these variations, that is, making

$$C = 2.D + 1.E + F,$$

the entire scheme becomes this :—

$$\begin{aligned}
1.5874011 &= A = 1.B + 0.C + D \\
1.2599210 &= B = 1.C + 0.D + E \\
1.0000000 &= C = 2.D + 1.E + F \\
.3274801 &= D = 1.E + 0.F + G \\
.2599210 &= E = 2.F + 1.G + H \\
851188 &= F = 1.G + 0.H + I \\
675591 &= G = 2.H + 1.I + K \\
221243 &= H = 1.I + 0.K + L \\
175597 &= I = 2.K + 1.L + M \\
57508 &= K = 1.L + 0.M + N \\
45646 &= L = 2.M + 1.N + O \\
14935 &= M = 1.N + 0.O + P \\
11862 &= N = 2.O + 1.P + Q \\
3914 &= O = 1.P + 0.Q + R \\
3073 &= P = 2.Q + 1.R + S \\
961 &= Q = 1.R + 0.S + T \\
841 &= R = 2.S + 1.T + U \\
310 &= S = 1.T + 1.U + V \\
120 &= T \\
101 &= U \\
89 &= V
\end{aligned}$$

in which the pair of groups of quotients

$$\left\{ \begin{matrix} 1, & 0, & 1 \\ 2, & 1, & 1 \end{matrix} \right\}$$

is repeated almost to the end, ceasing only when the accumulation of the last-place inaccuracies may have interfered. Hence we are led to assume that this recurrence ought to continue for ever. The soundness of this inference is confirmed when we operate on the symbolical representatives of the three quantities.

Beginning with the three values, $A = \sqrt[3]{4}$, $B = \sqrt[3]{2}$, $C = 1$, and making $A = 1.B + 0.C + D$, $B = 1.C + 0.D. + E$, we find $D = \sqrt[3]{4} - \sqrt[3]{2}$, $E = \sqrt[3]{2} - 1$, and have now to operate on the three quantities C, D, E.

We have to enquire how often D may be contained in C. Now the quotients among them are not affected by any other alteration in value, provided they be all changed in the same ratio; therefore, exactly as in the analogous well-known operation for square-roots, we seek some multiplier which may render D rational. This multiplier is evidently $\sqrt[3]{4}+\sqrt[3]{2}+1$, and the new proportionate values of C, D, E become $C'=\sqrt[3]{4}+\sqrt[3]{2}+1$, $D'=\sqrt[3]{2}$, $E'=1$. Here we observe that D' is contained in $\sqrt[3]{4}+\sqrt[3]{2}$ twice, while E' is contained in 1 once, wherefore we write $C'=2.D'+1.E'+F'$ giving $F'=\sqrt[3]{4}-\sqrt[3]{2}$; and thereafter putting $D'=1.E'+0.F'+G'$ we find $G'=\sqrt[3]{2}-1$. Here, again, we see that the E', F', G' are transcripts of the previous C, D, E, and that thus the group of quotients

$$\left\{\begin{matrix} 2, & 1, & 1 \\ 1, & 0, & 1 \end{matrix}\right\}$$

must continually recur. This is concisely shown in the subjoined scheme.

$$\begin{array}{l|l|l l}
A = \sqrt[3]{4} & & & A = 1.B + 0.C + D \\
B = \sqrt[3]{2} & & & B = 1.C + 0.D + E \\
C = 1 & \sqrt[3]{4}+\sqrt[3]{2}+1 & & \left\{ C = 2.D + 1.E + F \right. \\
D = \sqrt[3]{4}-\sqrt[3]{2} & \sqrt[3]{2} & & \left. D = 1.E + 0.F + G \right. \\
E = \sqrt[3]{2}-1 & 1 & \sqrt[3]{4}+\sqrt[3]{2}+1 & \left\{ E = 2.F + 1.G + H \right. \\
F & \sqrt[3]{4}-\sqrt[3]{2} & \sqrt[3]{2} & \left. F = 1.G + 0.H + I \right. \\
G & \sqrt[3]{2}-1 & 1 & \text{and so on.} \\
H & & \sqrt[3]{4}-\sqrt[3]{2} & \\
I & & \sqrt[3]{2}-1 &
\end{array}$$

It follows from this, that the values of F and G are less than those of D and E in the ratio of $\sqrt[3]{2}-1:1$; while those of H and I are again less in the same ratio, so that the series D, F, H . . . . . as also E, G, I . . . . . form geometrical progressions having the common ratio $\sqrt[3]{2}-1$; and, writing for shortness' sake $e=\sqrt[3]{2}-1$, we have $D=e\sqrt[3]{2}$, $E=e$; $F=e^2\sqrt[3]{2}$, $G=e^2$; $H=e^3\sqrt[3]{2}$, $I=e^3$; and so on.

By successive substitutions we obtain the simultaneous values of A, B, C as shown in the subjoined scheme. In the lower part of it the numerical coefficients alone are written.

1.A								
1.B	+ 0.C	+ 1.D	1.B					
1.C	+ 1.D	+ 1.E	1.C	+ 0.D	+ 1.E	1.C		
3.D	+ 2.E	+ 1.F	2.D	+ 2.E	+ 1.F	2.D	+ 1.E	+ 1.F
5.E	+ 1.F	+ 3.G	4.E	+ 1.F	+ 2.G	3.E	+ 1.F	+ 2.G
11.F	+ 8.G	+ 5.H	9.F	+ 6.G	+ 4.H	7.F	+ 5.G	+ 3.H
19.G	+ 5.H	+11.I	15.G	+ 4.H	+ 9.I	12.G	+ 3.H	+ 7.I
43.H	+30.I	+19.K	34.H	+24.I	+15.K	27.H	+19.I	+12.K
73.I	+19.K	+43.L	58.I	+15.K	+34.L	46.I	+12.K	+27.L
165	116	73	131	92	58	104	73	46
281	73	165	223	58	131	177	46	104
635	446	281	504	354	223	400	281	177
1081	281	635	858	223	504	681	177	400
2443	1716	1081	1939	1362	858	1539	1081	681
4159	1081	2443	3301	858	1939	2620	681	1539
9399	6602	4159	7460	5240	3301	5921	4159	2620
16001	4159	9399	12700	3301	7460	10080	2620	5921

Omitting each alternate line of these values, we form a continuous series as shown below :—

A.			B.			C.		
1.C	1.D	1.E	1.C	0.D	1.E	1.C		
5.E	1.F	3.G	4.E	1.F	2.G	3.E	1.F	2.G
19.G	5.H	11.I	15.G	4.H	9.I	12.G	3.H	7.I
73.	19.	43.	58.	15.	34.	46.	12.	27.
281.	73.	165.	223.	58.	131.	177.	46.	104.
1081.	281.	635.	858.	223.	504.	681.	177.	400.
4159.	1081.	2443.	3301.	858.	1939.	2620.	681.	1539.
16001.	4159.	9399.	12700.	3301.	7460.	10080.	2620.	5921.
e^{n-1}	$e^n\sqrt[3]{2}$	e^n	e^{n-1}	$e^n\sqrt[3]{2}$	e^n	e^{n-1}	$e^n\sqrt[3]{2}$	e^n
1	$\sqrt[3]{4}-\sqrt[2]{2}$	$\sqrt[3]{2}-1$	1	$\sqrt[3]{4}-\sqrt[3]{2}$	$\sqrt[3]{2}-1$	1	$\sqrt[3]{4}-\sqrt[3]{2}$	$\sqrt[3]{\ }\ -1$

A.			B.			C.		
1	2	2	1	1	2	1	1	1
5	6	8	4	5	6	3	4	5
19	24	30	15	19	24	12	15	19
73	92	116	58	73	92	46	58	73
281	354	446	223	281	354	177	223	281
1081	1362	1716	858	1081	1362	681	858	1081
4159	5240	6602	3301	4159	5240	2620	3301	4159
16001	20160	25400	12700	16001	20160	10080	12700	16001
$\sqrt[3]{4}$	$\sqrt[3]{2}$	1	$\sqrt[3]{4}$	$\sqrt[3]{2}$	1	$\sqrt[3]{4}$	$\sqrt[3]{2}$	1
$\sqrt[3]{4}\times e^{-n}$			$\sqrt[3]{2}\times e^{-n}$			e^{-n}		

and, collecting those terms involving $\sqrt[3]{4}$, $\sqrt[3]{2}$, we get this new scheme, which makes it clear that the numerical coefficients in the development of the powers of $\sqrt[3]{4} + \sqrt[3]{2} + 1$ give the desired approximations to the values of 1, $\sqrt[3]{2}$ and of $\sqrt[3]{4}$.

Those coefficients are readily found thus:—

We write the group

$$\begin{array}{ccc} 1, & 1, & 5 \\ 0, & 1, & 4 \\ 0, & 1, & 3 \end{array}$$

and continue the progression by adding the antepenult to the triples of the last and of the last but one term for the succeeding term, as

1	1	5	19	73	281	1081	4159	16001	etc.
0	1	4	15	58	223	858	3301	12700	etc.
0	1	3	12	46	177	681	2620	10800	etc.

If we follow the same method for the square-root, we find that the successive powers of $\sqrt{2}+1$, namely, $2\sqrt{2}+3$, $5\sqrt{2}+7$, $12\sqrt{2}+17$, and so on, have their coefficients approximating to the ratio of $1:\sqrt{2}$, thus $\frac{1}{1}, \frac{2}{3}, \frac{5}{7}, \frac{12}{17}$, etc. And if we proceed in the opposite direction we find similarly that the coefficients of the powers of $\sqrt[4]{3} + \sqrt[4]{4} + \sqrt[4]{2} + 1$ approximate to the ratio of 1, $\sqrt{2}$, $\sqrt[4]{4}$, $\sqrt[4]{8}$. The computation of these coefficients may be made neatly as in the adjoining scheme.

1	4	22	116	613	3240	17124	90504	etc.
1	5	26	138	729	3853	20364	107628	etc.
1	6	31	164	867	4582	24217	127992	etc.
1	7	37	195	1031	5449	28799	152209	etc.

Here the number at the head of one of the numbers in the preceding column, thus $613 = 116 + 138 + 164 + 195$. To this 613 we add the preceding 116 to get 729; to 729 we add 138 to get 867, and so on throughout. From four contiguous terms in any one line we may deduce the succeeding term by using the multipliers 1, 4, 6, 4; thus $1.22 + 4.116 + 6.613 + 4.3240 = 17124$.

The numbers shown in the last column give, between 90504 and its double 181008, three mean proportionals 107628, 127992, and 152209; and it is apparent that a fifth line deduced from the fourth one would be double of the first.

In the same way we may proceed to compute four geometrical means between a line and its double thus:—

1	5	35	235	1580	10626	71460	etc.
1	6	40	270	1815	12206	82086	etc.
1	7	46	310	2085	14021	94292	etc.
1	8	53	356	2395	16106	108313	etc.
1	9	61	409	2751	18501	124419	etc.

and we have the six numbers 71460, 82086, 94292, 108313, 124419, 142920 in continued proportion to within one-tenth part of unit in any of them.

The same process may be used for the roots of the number 3. Thus, if we write r for the n^{th} root of 3, and work out the successive powers of $(r^{n-1}+r^{n-2}+\ldots\ldots r^2+r^1+1)$ we shall find that the coefficients may be computed in a manner quite analogous to the preceding. Thus for $n=5$, that is, for $\sqrt[5]{3}$, the scheme is as under:—

1	5	45	365	2965	24141	196485	etc.
1	7	55	455	3695	30071	244767	etc.
1	9	69	565	4605	37461	304909	etc.
1	11	87	703	5735	46671	379831	etc.
1	13	109	877	7141	58141	473173	etc.

Here the number placed at the top of a column is the sum of the numbers in the preceding column, and the following terms are got by adding thereto the double of the preceding number, thus $365+2.45=455$; $455+2.55=565$, and so on, as is seen whenever we proceed to collect the surd elements of the successive powers of $\sqrt[5]{3^4}+\sqrt[5]{3^3}+\sqrt[5]{3^2}+\sqrt[5]{3}+1$; and it is manifest that the subsequent or sixth line would be just the triple of the first one. The approximation is, in this case, much slower than in the preceding.

The same method is applicable to the roots of rational fractions. Thus we may take the case of $\sqrt[5]{\frac{5}{3}}$, or as we may write it $\sqrt[5]{(1+\frac{2}{3})}$. The arrangement is thus:—

1	15	285	5295	98445	etc.
1	17	315	5865	109035	etc.
1	19	349	6495	120765	etc.
1	21	387	7193	133755	etc.
1	23	429	7967	148141	etc.

Here the new column is headed by the triple of the sum of the numbers in the previous column; and the rest of the column is got by adding the doubles of the adjoining figures.

Thus it seems that the comparison of several quantities in continued proportion leads us to this general conclusion that, if r be the n^{th} root of a number or of a rational fraction, and if the powers of

$$r^{n-1} + r^{n-2} + \ldots + r^2 + r + 1$$

be expanded, the numerical coefficients of the several surds are approximately proportional inversely to the values of the surds themselves: the approximation being closer as the index of the power is augmented.

Meetings of the Royal Society—Session 1890–91.

Monday, 24th November 1890.

General Statutory Meeting. Election of Office-Bearers. *P.* xviii. 1.

Monday, 1st December 1890.

Sir Douglas Maclagan, M.D., President, in the Chair.

1. The President gave an Opening Address. *P.* xviii. 2.

The following Communications were read :—

2. Obituary Notice of Professor Hermann Kolbe. By Prof. Crum Brown. *P.* xvii. p. xxxv.

3. On an Analytical Examination of Manganese Nodules, with special reference to the Presence of the Rarer Elements. By John Gibson, Esq., Ph.D.

4. On the Occurrence of Sulphur in Marine Muds and Nodules, and its Bearing on their Modes of Formation. By J. Y. Buchanan, F.R.S. *P.* xviii. 17.

5. Anatomical Description of Two New Genera of Aquatic Oligochæta. By Frank E. Beddard, M.A. Oxon. *T.* xxxvi. 273.

6. On a Simple Pocket Dust-Counter. By J. Aitken, F.R.S. *P.* xviii. 39.

The following Candidates for Fellowships were balloted for, and declared duly elected Fellows of the Society :—

Henry Hannotte Vernon, M.D.
J. H. Fullarton, M.A., D.Sc.
Joshua Law Kerr, M.D.
James Walker, D.Sc., Ph.D.
Alexander Smith, Ph.D.
Charles A. Cooper.

Monday, 15th December 1890.

Professor Crum Brown, Secretary, in the Chair.

The following Communications were read :—

1. On the Extension of Brouncker's Method to the Comparison of Several Magnitudes. By E. Sang, Esq., LL.D. *P.* xviii. 341.

2. Proposed Extensions of Quaternion Powers of Differentiation. By Alexander M'Aulay, Ormond College, Melbourne. Communicated by Professor Tait. *P.* xviii. 98.

3. Exhibition of a Model illustrating a Molecular Theory of Magnetism. By Professor EWING, F.R.S.

4. On the Development of Adenoid Tissue. By Dr GULLAND. Communicated by Dr A. BRUCE.

Monday, 5th January 1891.

Professor Chrystal, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. Obituary Notices—

   Sir HENRY YULE. By COUTTS TROTTER, Esq. *P.* xvii. p. xliii.

   Dr JAMES DUNCAN MATTHEWS. By Professor M'INTOSH, F.R.S. *P.* xvii. p. xxxviii.

   Rev. JAMES GRANT, D.C.L. By A. B. BELL, Advocate. *P.* xvii. p. xxxii.

2. On the Soaring of Birds ; a continuation of the letter from the late Mr W. FROUDE to Sir W. THOMSON. *P.* xviii. 65.

3. Further Note on Impact. By Professor TAIT.

Friday, 9th January 1891.

Professor Chrystal, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. On the Form, Structure, and Distribution of Manganese Nodules in the Deep Sea (with Specimens). By Dr JOHN MURRAY.

2. On the Occurrence of Manganese Deposits in Marine Muds. By ROBERT IRVINE, F.C.S., and Dr JOHN GIBSON. *P.* xviii. 54.

3. On the Composition of Oceanic and Littoral Manganese Nodules. By J. Y. BUCHANAN, Esq., F.R.S. *T.* xxxvi.

4. On the Composition of some Deep-Sea Deposits from the Mediterranean. By J. Y. BUCHANAN, Esq., F.R.S. *P.* xviii. 131.

5. On the Action of Metallic Salts on Carbonate of Lime (with illustrative Specimens). By ROBERT IRVINE, F.C.S., and W. S. ANDERSON, Esq. *P.* xviii. 52.

Monday, 19th January 1891.

The Hon. Lord M'Laren, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. Obituary Notice, JAMES LESLIE, Memb. Inst. C.E. By ALEXANDER LESLIE, C.E. *P.* xviii. p. xvii.

2. On Berberine. By Professor W. H. Perkin, F.R.S.
3. On some hitherto unproved Theorems in Determinants. By Thomas Muir, LL.D. *P.* xviii. 73.
4. On a Problem of Elimination connected with Glissettes of the Ellipse and Hyperbola. By Thomas Muir, LL.D.
5. The Equation of the Glissette of the Curve $\frac{x^n}{a^n}+\frac{y^n}{b^n}=1$, when the Guides are the Axes of Coordinates. By the Hon. Lord M'Laren. *P.* xviii. 83.

Monday, 2d February 1891.

Sir Douglas Maclagan, M.D., President, in the Chair.

At the request of the Council, Professor Rutherford gave an Address

On the Sense of Hearing.

The following Candidate for Fellowship was balloted for, and declared to be a duly elected Fellow of the Society :—

John B. Clark, M.A.

Monday, 16th February 1891.

A. Forbes Irvine, Esq., LL.D., in the Chair.

The following Communications were read :—

1. Further Note on the Virial. By Professor Tait.
2. Haycraft's process for the Estimation of Uric Acid. A Reply to the Adverse Criticism of Salkowski and Jolin, and a Review of the favourable Notices of Hermann, Czapek, and Camerer. By John Berry Haycraft, M.D., D.Sc. *P.* xviii. 255 (*Abstract*).
3. Note on Potassium Persulphate. By H. Marshall, D.Sc. *P.* xviii. 63.
4. On the Interaction of Longitudinal and Circular Magnetisations in Iron and Nickel Wires. (Second Note.) By Professor Cargill G. Knott. *P.* xviii. 124.
5. Professor Kelland's Problem on Superposition. By Robert Brodie, Esq. Communicated by Professor Tait. *T.* xxxvi. 307.
6. On the Temperature of the Salt and Fresh Water Lochs of the West of Scotland at Different Depths and Seasons, during the years 1887 and 1888. By John Murray, LL.D. *P.* xviii. 139.
7. A New Method for the Estimating the Specific Gravity of the Blood. By John Berry Haycraft, M.D., D.Sc. *P.* xviii. 251.

Monday, 2nd March 1891.

Sir Douglas Maclagan, M.D., President, in the Chair.

The following Communications were read :—

1. On the Influence of High Winds on the Barometer at the Ben Nevis Observatory. By ALEXANDER BUCHAN, LL.D. *P.* xviii. 88.
2. On a Human Cyclops. By Dr ALEXANDER BRUCE.
3. Cases illustrating the Position of the Visual Centre in Man. By Dr BYROM BRAMWELL.
4. On the Anatomy of Ocnerodrilus (*Eisen*). By F. BEDDARD, M.A., F.Z.S. *T.* xxxvi.

The following Candidates for Fellowship were balloted for, and declared duly elected Fellows of the Society :—

The Hon. Lord KYLLACHY.
Professor JOHN RANKINE, Advocate.
Professor R. M. WALMSLEY, D.Sc.
Professor R. STANFIELD.
Sir JAMES SAWYER, Knight, M.D. (Lond.).
The Hon. Lord STORMONTH-DARLING.

Monday, 16th March 1891.

The Rev. Professor Flint, Vice-President, in the Chair.

The following Communications were read :—

1. On Bi-stratification in the Living Greek Language. By Professor BLACKIE.
2. On Silica and the Siliceous Remains of Organisms in Modern Seas. By JOHN MURRAY, LL.D., Ph.D., &c., and ROBET IRVINE, F.C.S. *P.* xviii. 229.
3. On the Relation of Nerves to Odontoblasts, and on the Growth of Dentine. By W. G. AITCHISON ROBERTSON, M.D., B.Sc. Communicated by Sir WILLIAM TURNER, F.R.S. *T.* xxxvi. 321.
4. On the Comparative Value of African Lands. By A. SILVA WHITE, Esq.

Monday, 6th April 1891.

The Hon. Lord Maclaren, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. Obituary Notice of Professor CAMPBELL SWINTON. By The Rt. Hon. Lord MONCREIFF of Tulliebole, Hon. Vice-President. *P.* xviii. p. i.

2. Synthesis of Dibasic Acids by means of Electrolysis. Alkyl Derivatives of Succinic Acid. By Professor Crum Brown and Dr James Walker. *P.* xviii. 95 (*Abstract*).

3. On the Virial Equation, with special reference to Carbonic Acid. By Professor Tait.

The following Candidates for Fellowship were balloted for, and declared duly elected Fellows of the Society:—

John Hardie Wilson, D.Sc.
John Macallan, F.I.C.

Monday, 4th May 1891.

Sir Douglas Maclagan, M.D., President, in the Chair.

The following Communications were read:—

1. A Comparison of the Minute Structure of Plant Hybrids with that of their Parents, and its bearing on Biological Problems. (Illustrated by three Parallel Lantern Demonstrations.) By J. M. Macfarlane, D.Sc.

2. On a Method of Observing and Counting the Number of Water Particles in a Fog. (Preliminary Note.) By John Aitken, F.R.S. *P.* xviii. 259.

The following Candidates for Fellowship were balloted for, and declared duly elected Fellows of the Society:—

Richard D. Graham.
T. Wemyss Fulton, M.B.

Monday, 18th May 1891.

The Hon. Lord M'Laren, LL.D., Vice-President, in the Chair.

The following Communications were read:—

1. The barometer at the Ben Nevis Observatory, in relation to the Direction and Force of the Wind. By Alexander Buchan, LL.D.

2. An Account of some Experiments which show—(I.) That the Displacements of the Heart, which since Harvey's time are supposed to take place with every Contraction, do not really occur in the unopened Chest. (II.) That the Cardiogram has been misinterpreted by Physiologists. By John Berry Haycraft, M.D., D.Sc.

3. The Clyde Sea Area:—Part I. Physical Geography. Part II. Salinity and Chemical Composition. By Hugh Robert Mill, D.Sc. *T.* xxxvi.

Monday, 1st June 1891.

Professor Chrystal, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. The Violet of the Solar Spectrum. By C. PIAZZA SMYTH, LL.D., F.R.S.E.

2. On the Fossil Plants of the Kilmarnock, Galston, and Kilwinning Coal Field, Ayrshire. By ROBERT KIDSTON, F.R.S.E., F.G.S.

3. On Some Relations between Magnetism and Twist. Parts II. and III. By C. G. KNOTT, D.Sc., F.R.S.E., Professor of Natural Philosophy in the Imperial University of Tokyo, Japan. *T.* xxxvi. 485.

4. The Winds of Ben Nevis. By R. T. OMOND, F.R.S.E., Superintendent of Ben Nevis Observatory, and ANGUS RANKIN. *T.* xxxvi.

5. On the Blood of the Invertebrata. By Dr A. B. GRIFFITHS, F.R.S.E., F.C.S., &c. *P.* xviii. 288.

Monday, 15th June 1891.

T. B. Sprague, Esq., M.A., in the Chair.

The following Communications were read :—

1. A Case of Defective Endochondral Ossification in a Human Fœtus. By JOHNSON SYMINGTON, M.D., and HENRY ALEXIS THOMSON, M.D. *P.* xviii. 271.

2. The Alkaline and Acid Salts of the Blood and Urine, and especially those of Phosphoric Acid. By JOHN BERRY HAYCRAFT, M.D.

3. On an Optical Proof of the Existence of Suspended Matter in Flames. By Sir GEORGE G. STOKES, Bart., F.R.S. (In a letter to Prof. Tait.) *P.* xviii. 263.

4. Observations on Vegetable and Animal Cells; their Structure, Division, and History. Part II. By J. M. MACFARLANE, D.Sc.

5. A Comparison of the Minute Structure of Plant Hybrids with that of their Parents, and its Bearing on Biological Problems. (Illustrated by three Parallel Lantern Demonstrations.) Part II. By J. M. MACFARLANE, D.Sc.

Monday, 6th July 1891.

The Hon. Lord M'Laren, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. On the Solid and Liquid Particles in Clouds. By JOHN AITKEN, F.R.S. *T.* xxxv. 313.

2. A Demonstration of Lagrange's Rule for the Solution of a Linear Partial Differential Equation; with some Historical Remarks on Defective Demonstrations hitherto Current. By Professor CHRYSTAL, LL.D. *T.* xxxvi.

3. On the Foundations of the Kinetic Theory of Gases, V.
   (*a*) On the Isothermals of Ethyl-Oxide. *P.* xviii. 265.
   (*b*) On the Application of the Virial Method to System of Doublets, Triplets, &c.
   (*c*) On the Mechanism of Equilibrium between Liquid and Saturated Vapour.

   By Professor Tait.

4. The Maltese Fossil *Echinoidea*, and their Evidence on the Correlation of the Maltese Rocks. By J. W. Gregory, F.G.S., of the British Museum. Communicated by Dr John Murray. *T.* xxxvi.
5. On the Lateral Sense-Organs of *Læmargus Acanthias.* I. The Sensory Canals. By Professor Ewart.
6. The Electric Resistance of Cobalt at High Temperatures. By Professor C. G. Knott. *P.* xviii. 303.
7. The Thermo-electric Positions of Cobalt and Bismuth. By Professor C. G. Knott. *P.* xviii. 310.

The following Candidate for Fellowship was balloted for, and declared to be a duly elected Fellow of the Society :—

Robert Munro, M.A., M.D.

Wednesday, 15th July 1891.

Sir Douglas Maclagan, M.D., President, in the Chair.

The following Communications were read :—

1. A New Ship for the Study of the Sea. By His Serene Highness Prince Albert of Monaco. *P.* xviii. 295.
2. Sur les Résultats zoologiques des Campagnes de l'*Hirondelle.* Par M. le Baron Jules de Guerne.

   [These two Papers were given at the Request of the Council; and the second was illustrated by Lantern Projections.]

3. A Cartographic Device of great use in the treatment of some Geographical and Telluric Problems. By J. Y. Buchanan, F.R.S.
4. An Account of a Deep-Sea Tow-Net. By W. E. Hoyle, M.A., M.R.C.S.
5. Exhibition of an Improved Self-Locking Water-Bottle. By Dr H. R. Mill.

Monday, 20th July 1891.

The Hon. Lord M'Laren, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. Obituary Notice of Professor C. I. Burton. By William Marshall. Communicated by Professor Geddes. *P.* xviii. p. xxi.

2. Additional Observations on the Development and Life-Histories of the Marine Food-Fishes, and the Distribution of their Ova. By Professor M'INTOSH, F.R.S. *P.* xviii. 268. (*Abstract.*)

3. On the Bright Streaks on the Moon. By Professor RALPH COPELAND, Astronomer-Royal for Scotland.

4. On the Effect of Longitudinal Magnetisation on the Interior Volume of Iron and Nickel Tubes. By Professor C. G. KNOTT. *P.* xviii. 315.

5. Further Remarks on the Relation between Kinetic Energy and Temperature. By Professor TAIT.

Donations to the Library of the Royal Society from 1889 to 1891.

I. Transactions and Proceedings of Learned Societies, Academies, &c.

Adelaide.—Philosophical Society, Transactions and Proceedings. Vols. XII., XIII. 1888–90. 8vo.

University Calendar for 1890.

American Association for the Advancement of Science.—38th Meeting (Toronto, 1889).

Amsterdam.—Kon. Akademie van Wetenschappen. Verhandelingen. Afd. Natuurkunde. Dl. XXVII., XXVIII. 1889–90.—Afd. Letterkunde. Dl. XIX. 1890.—Verslagen en Mededeelingen, Natuurkunde. 3e Rks., Dl. VI., VII. 1889–90.—Letterkunde. 3e Rks., Dl. VI., VII. 1889–91.—Jaarboek, 1889–90.—Poemata Latina.

Kon. Zoologisch Genootschap "Natura Artis Magistra." Bijdragen. Festnummer, 1888.

Wiskundig Genootschap. Nieuw Archief voor Wiskunde, XVI., XVII., XVIII. 1890–91. Opgaven IV. 2–6; V. 1, 2.

Nieuwe Opgaven. Dl. V., Nos. 86–115.

Flora Batava. 287–294 Afleveringen.—*From the Dutch Government.*

Australia.—Australasian Association for the Advancement of Science. Reports, 1st and 2nd Meetings, 1888–90.

Intercolonial Medical Congress, Transactions. 2nd Session. 1889.

Baltimore—Johns Hopkins University.—American Journal of Mathematics. Vols. XII., XIII., and Index to Vols. I.–X. 1890–91. —American Chemical Journal. Vols. XII., XIII. 1890–91. Index to Vols. I.–X.—American Journal of Philology. Vols. X., XI., XII. 1. 1889–91.—Studies from the Biological Laboratory of the Johns Hopkins University. Vol. IV. 5–7. 1888. 8vo.—University Studies in Historical and Political Science. Vols. VIII., IX. 1890–91.—University Circulars. 1890–91.

Basel.—Naturforschende Gesellschaft. Verhandlungen. Bd. VIII. 3, IX. 1890. 8vo.

Batavia.—Magnetical and Meteorological Observatory. Observations. Vol. XII. 1889.—Regenwaarnemingen in Nederlandsch Indie. 11e Jaarg. 1889. 8vo.

Bataviaasch Genootschap van Kunsten en Wetenschappen. Verhandelingen. 8vo.

Batavia.—Tijdschrift voor Indische Taal-Land-en Volkenkunde. Deel XXXIII., XXXIV. 1890–91. 8vo.
Notulen, Deel XXVIII. 1890.
Kon. Natuurkundig Vereeniging. Natuurkundig Tijdschrift voor Nederlandsch Indie. Dl. XLIX. 8vo.

Belfast.—Natural History and Philosophical Society. Proceedings, 1889–90.

Bergen.—Museum's Aarsberetning for 1889. 8vo.

Berlin.—Königliche Akademie der Wissenschaften. Abhandlungen, 1889–90.—Sitzungsberichte. 1889–91.
Physikalische Gesellschaft. Fortschritte der Physik im Jahre 1883, 1884. 1te Abtheil.—Allgemeine Physik, Akustik. 2te Abtheil.—Optik, Wärmelehre, Elektricitätslehre. 3e Abtheil.—Physik der Erde. Berlin. 8vo.—Verhandlungen. 1888–89.
Zeitschrift der Deutschen Meteorologischen Gesellschaft. 1889–91. 8vo.
Preussisches Meteorologisches Institut. Ergebnisse der Meteorologischen Beobachtungen in Jahren 1888–91. 4to.—Abhandlungen. Bd. I., Nos. 1–3. 1890.
Das Königl. Preussische Meteorologische Institut und dessen Observatorium bei Potsdam, von W. von Bezzold. 1890. 4to.

Bern.—Beiträge zur geologischen Karte der Schweiz. Lief XVI. 1890. 4to.—*From the Commission Fédérale Géologique.*
Naturforschende Gesellschaft. Mittheilungen. Nos. 1215–1264. 1889–90. 8vo.

Berwickshire.—Berwickshire Naturalists' Club. Proceedings. Vol. XII. 2, 3. 1890–91. 8vo.

Birmingham.—Philosophical Society. Proceedings. Vol. VII. 1890. 8vo.

Bologna.—Accademia d. Scienze dell' Istituto di Bologna.
Memorie. Ser. IV., Tom. X. 1889.—Indice Generale. 1880–89.
Calendrier Universel et Méridien Universel: Rapports. 1890–91.

Bombay.—Bombay Branch of the Royal Asiatic Society, Journal. Vol. XVIII. 1891.
Magnetical and Meteorological Observations made at the Government Observatory for 1888–89. Bombay. 4to.
Natural History Society, Journal. Vols. V., VI. 1890–91.

Bonn.—Verhandlungen des Naturhistorischen Vereines der Preussischen Rheinlande und Westfalens. 1890–91. 8vo.

Bordeaux.—Société des Sciences Physiques et Naturelles, Mémoires. 3e Sér., Tom. IV., V. 1. 1888–89.

Bordeaux.—Société de Géographie Commerciale, Bulletin. 1890–91. 8vo.

Boston.—Boston Society of Natural History, Memoirs. Vol. IV. 7–9. 1890–91. 4to.—Proceedings. Vol. XXIV. 1888–90. 8vo.
American Academy of Arts and Sciences, Proceedings. Vols. XXIII.–XXV. 1888–90.

Brera.—See *Milan.*

British Association for the Advancement of Science.—Report of the Meetings at Newcastle-on-Tyne, 1889, Leeds, 1890.

Brunswick.—Verein für Naturwissenschaft, Jahresbericht. 1887-89.

Brussels.—Académie Royale des Sciences, des Lettres, et des Beaux-Arts de Belgique, Bulletin. Tomes LIX.–LXI. 1890–91. 8vo.—Mémoires Couronnés et Autres Mémoires. Tomes XLIII.–XLV. 1889–91.—Mémoires Couronnés et Mémoires des Savants Étrangers. Tomes L., LI. 1889–90. 4to.—Biographie Nationale. Tome XI. 1891. 8vo.—Annuaire. Année, 1890–91. 8vo.

Observatoire Royal, Annuaire. Années, 1890–91. 8vo.

Société Scientifique de Bruxelles, Annales. Années, 1888–89, 1889–90. 8vo.

Musée Royal d'Histoire Naturelle de Belgique, Bulletin. Tome V. 1. 1886. 8vo.

Bucharest.—Academia Romana. Extrasu din Analele, Memorii si Notite. Tom. XI., XII. 1889–90.—Also Documents relating to the History of Roumania. 1889–91.

Analele Institutului Meteorologic al Romaniei. Tom. IV. 1888. (In French and Roumanian.)

Buda-Pesth.—Konigl. Ungarische Naturwissenschaftliche Gesellschaft, Berichte. Bd. IV.–VII. 1886–90.

Hungarian Academy of Sciences.—Memoirs, 1890 ; Bulletins, 1890, and other Publications of the Hungarian Academy, or published under its auspices.

Mathematische und naturwissenschaftliche Berichte aus Ungarn. Bd. VII. 1889.

Ungarische Revue. 1890.

Archæological Bulletin. Tom. VIII., IX., X.

Buenos-Aires.—Anales de la Oficina Meteorologica Argentina. Tom. VII., VIII. 1889–91. 4to.

Anales del Museo Nacional de Buenos Ayres. Tom. III. 1890–91.

Calcutta—Asiatic Society of Bengal.—Proceedings. 1889–91. 8vo.—Journal (Philology and Natural History). Vols. LIX., LX. 1890–91. 8vo.

Indian Museum.—Catalogue of the Mantodea, by J. Wood-Mason. Pt. II. 1891.

Monograph of Oriental Cicadidæ, by W. L. Distant. Pts. II., III. 1890–91.—Catalogue of Mammalia. Pt. II.

Royal Botanic Gardens.—The Species of Ficus of the Indian Malayan and Chinese Countries, by George King. Appendix I., II. 1889. Fol.—Annals. Vol. II. The Species of Artocarpus indigenous to British India. The Indo-Malayan species of Quercus and Castanopsis, by G. King. Fol. 1889. —See also *Indian Government.*

California.—Academy of Sciences, Proceedings. 2nd Ser. Vol. II. 1889. Occasional Papers. Nos. 1, 2.

State Mining Bureau : Annual Reports. 1889–90.

California.—University of California. Bulletins and Biennial Reports. 1875 *et seq.*—Reports of Agricultural College. 1888 *et seq.*—And Miscellaneous Pamphlets.

Lick Observatory. Reports on the Total Eclipse of the Sun of January 1889.

Cambridge.—Philosophical Society, Transactions. Vol. XV. 1. 1891. 4to.—Proceedings. 1890–91. 8vo.

Cambridge (U.S.).—*Harvard College.*—Museum of Comparative Zoology at Harvard College, Annual Reports. 1888–89, 1889–90.—Bulletin. Vols. XVIII.-XXI. 1889–91. 8vo.—Memoirs. Vol. XVI., No. 3. Genesis of the Aretidæ, by A. Hyatt. 1890. 4to.—Vol. XVII., No. 1. The Immature State of Odonata. Part 3. Sub-family Cordulina, by Louis Cabot. 1890. 4to.

Bulletins. Vols. V., VI. 1890–91.—Circulars. Vols. VII., VIII.

Annals of the Astronomical Observatory at Harvard College. Vols. XXI. 1, 2, XXII., XXIII. 1, XXIV., XXVII., XXX. 1. 1888–90.

Canada.—The Royal Society of Canada, Proceedings and Transactions. Vols. VII., VIII. 1889–90.

Geological Survey of Canada. Reports of Progress, 1887–88, 1888–89. 8vo. Canadian Palæontology, by J. F. Whiteaves. Vol. I. 3, Vol. III. 1. 1891.—Micro-Palæontology of Cambro-Silurian Rocks. 1883.—Descriptive Catalogue of Canadian Plants. Pt. 5. Acrogens, by J. Macoun. 1890.—*From the Government of the Dominion.*

Canadian Society of Civil Engineers, Transactions. Vol. IV. 1891.

Cassel.—Verein für Naturkunde, Bericht. 1889–90.

Catania.—Atti dell' Accademia Gioenia di Scienze Naturali. Ser. 4ª, Tom. I., II. 1889–90. 4to.

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OBITUARY NOTICES.

OBITUARY NOTICES.

Archibald Campbell Swinton of Kimmerghame. By The Right Hon. Lord Moncreiff of Tulliebole.

I am desirous of placing on the records of the Royal Society, in the shape of an obituary notice, a slender memorial of a very early, a very constant, and a very distinguished friend, who at his death, on the 27th November of last year, was one of the oldest members of this Society. The subject of my memoir is the late Mr Archibald Campbell Swinton of Kimmerghame, who was admitted a member in 1844, and died in his 78th year. He was possessed of a character and abilities which, although not conversant with much public display, were not only of solid power, but of the more ethereal element, and which, had his surroundings required or prompted, might have raised him to great eminence. It may truly be said of him, though the saying is commonplace, that he touched nothing in his long, busy, and useful life which he did not adorn. Perhaps ease, by itself, may have tended to repress the genial current of his soul, as for the last five and twenty years of his life the position of an active, cultured, and energetic country gentleman was that which fate had prepared for him; but he had a buoyancy and vivacity of intelligence which would have lighted up the most commonplace occupation, and would have asserted itself in the dingiest of surroundings.

He came of an ancient and honourable house, who were territorial magnates in the south of Scotland through many centuries, and are mentioned as having taken part in many public events in a work substantially compiled by the subject of this memoir, called *The Swintons of that Ilk.* In that volume the family, and the history of the descent of their estates, as well as of the collateral branches, are very clearly deduced, and as a piece of historical reading it is

interesting and even amusing. It starts about the thirteenth century, and brings the narrative down through more than a score of descents to comparatively recent times. There were members of the family to be found in all positions which the well-born Scot frequented or patronised in those days. There were Swintons in the army and in the navy, at the Scottish bar and on the Scottish bench, in the French Guard, and in the historic feuds and frays of their borderland. Scott mentions the chief of the Swintons as engaged in the battle of Otterburn—

> " When Swinton laid his lance in rest,
> Which tamed of yore the sparkling crest
> Of Clarence's Plantagenet."

One could construct an interesting paper out of the materials contained in this volume. Some of the passages are marked by a certain grim humour. One of the most eccentric of the Swintons, who are commemorated and passed in array in this volume, is one John Swinton of Swinton, who flourished, if he could be said to flourish, during the Commonwealth and the subsequent troubles. A strong, self-willed, and restless man, who fought and did not fight, now with the Covenanters and now with the Royalists, and at last, as he seemed to agree with neither, compromised matters by becoming a Quaker, and undergoing many persecutions in consequence. Among other visitations he was attainted as a traitor, but the attainder was recalled in favour of his son. He is said to have been high in the confidence of Cromwell. John Swinton, the father of Mr Campbell Swinton, was descended from the fourth son of this John Swinton of Swinton, named Archibald, who in his younger years had repaired to India, and on his return purchased the estate of Kimmerghame, which had belonged to a family of Hume.

In 1829 the family estate of Swinton was sold, for the first time in 700 years. It was purchased by Mr George Swinton, one of the old family. John Swinton had been intended for the Bar, but he ultimately entered the army, and after his father's death in 1803, the estate of Kimmerghame having been sold by his father shortly before, purchased the estate of Broadmeadows in Berwickshire. This he sold in 1825, and thereafter resided with his family in Edinburgh in a house No. 16 Inverleith Place, which he had built for himself. He had two sons, of whom the subject of

the present memoir was the elder, and several daughters. I remember, as a schoolboy of nine or ten years of age, seeing his mother, Mrs Swinton, in my father's house in Northumberland Street, in Edinburgh, and being singularly impressed with her sweetness and charm of manner. She was a grand-daughter of Mure of Caldwell, and thus the two families, the Mures and the Swintons, were closely connected. Mrs Swinton had come to spend the evening with my mother, and the tidings of her death a few days thereafter gave my susceptibilities a shock which I long remembered.

Archibald Swinton, afterwards Archibald Campbell Swinton, the eldest son, was born on 15th July 1812, and at the age of eight was sent to a preparatory school in Yorkshire, near Doncaster, of which the headmaster was a Dr Sharp, a scholar of some eminence. He was vicar of Doncaster, and the school over which he presided had high reputation. Along with other pupils were the present Lord Grimthorpe and his two brothers, Christopher and William Beckett Denison. Among the papers at Kimmerghame is a letter, dated 15th January 1827, from Dr Sharp to John Swinton. He writes as follows :—

"No pupils I ever had gave me more cordial satisfaction during the time they were under my care than your sons, and it delighted me extremely to receive so favourable an account of their present prospects. So far as assiduity and applied industry can prevail, James, I know, will never be found deficient; but Archie, if in abilities and quickness of apprehension so much his superior, requires a little more management to bring into full employment those excellent powers of memory and understanding with which fate has endowed him—*aut Cæsar aut nullus* used to be his maxim here; and of this I feel sure, that no boy of his own age can cope with him if Archie be not wanting to himself."

Swinton remembered with gratitude and affection his life at Doncaster; and he was wont to describe the appearance of the Archbishop of York on his way to Doncaster races, which it seems the archbishops were formerly sometimes in the habit of frequenting. He afterwards went for a short time to reside with a gentleman near Hitchin, but he does not appear to have remained long there. The well-known school called the Edinburgh Academy was opened in 1824, and Swinton was sent to it in, I think, 1825. He ever afterwards took the warmest interest in its welfare, and was one of the Directors down to the day of his death. From

school he went to the University of Edinburgh, and in the Humanity Class of Professor Pillans my acquaintance, or rather friendship, with him commenced, and it continued unbroken down to the end. A very bright, attractive, and able band they were, that contribution from the new school. Some made their mark in the world thereafter. The most prominent of them were, in addition to Swinton himself, William Aytoun, the author of the *Lays of the Cavaliers*, and afterwards Professor of Rhetoric in the University of Edinburgh; George Makgill of Kemback; John Balfour Melville of Mount Melville; and John Thomson Gordon, who was afterwards Sheriff of Edinburgh. Archibald Campbell Tait, a cousin of Swinton's, and the future Archbishop of Canterbury, was his class-fellow at the Edinburgh Academy, but went to Glasgow University, though he afterwards rejoined the circle in the summer in the ranks of the debating club entitled the Classical Society. Among other comrades was numbered a man of some subsequent reputation, and quite as good company as any of them—Samuel Warren, the author of *Ten Thousand a Year*. He remained for two years among us, and then disappeared, but had not been long gone, when the "*Diary of a Late Physician*" burst upon us. I do not know whether admiration or exasperation at our companion's sudden fame was the prevalent feeling; we were indeed raised in our own esteem to have lived so near the rose, but exasperated also by not having found him out. But he was a man worth knowing, and we met elsewhere afterwards.

The Classical Society was founded by a knot of students in the Latin Class in Edinburgh about the year 1827. Swinton, I think, joined it during its second year. They were an unassuming but resolute band of students, who cultivated oratory under some disadvantage in a dingy class-room of the old High School, by the light of a single tallow candle. It had been originally intended by the founders that the debates should be in Latin, but, after two or three attempts the efforts were too spasmodic to witness, and the vernacular was resumed. At the risk of some anticipation I must quote some lines from Swinton's pen on the origin of this primitive parliament, partly because they show the historian at his best, and partly from their thorough fidelity. I am indebted to the family for the manuscript book which contains among others the perform-

ance from which I am about to quote. Thus sings the classic bard of our first beginnings in the Classical:—

"'Twere vain to take the task from history's page,
And tell our progress on from youth to age;
But oft by future poets shall be sung
The time when e'en the Classical was young;
When closely ranged on dusky benches sate
The beardless arbiters of Britain's fate,
And, as to mock the dying light of day,
One tallow candle shed a flickering ray
From off the desk whence not an hour before
Carson had poured the tide of classic lore.
That tallow candle was an emblem fit
Of those who used beneath its glow to sit,—
Poor, slow, uncertain, solitary, dim,
As were the nascent energies of him
Who, all untaught to plead a party's cause,
Glanced at the Chair, and thought he saw the tawse;
Then trembling rose, and from his lips just sent
The old exordium, 'Mr President'—
Looked at his notes, cough'd, hemmed with thoughtful frown,
Looked at his notes again,—and then sat down!"

These lines are contained in an address written for a supper of the Classical Society several years afterwards. The volume from which I quote contains many similar performances. These were the days of the first Reform Bill. Swinton was always a Tory of the bluest dye; but he was the most liberal Tory I ever knew. He has some lines of kindly greeting to his classical opponents among the passages to which I have referred, and some very kindly lines addressed to myself. He hated "the bill, the whole bill, and nothing but the bill," which was the Liberal cry in 1831, and he pleads that very laudable feeling in a letter which I had from him at the time, in which he justified himself for having blown to atoms the only woodcock which he had seen in a day's grouse shooting. He said he had the bill and the whole bill, but then he had nothing but the bill, the merit of which he did not see.

There are in this volume some very spirited lines in allusion to the French Revolution and the "tricolor," the last stanza of which is the following:—

"For the red is the rebel's appropriate hue,
The blue, livid envy's foul stain,
And the white is pale terror that trembles to do
The deeds the base heart can contain;

But the red rose of England, and Scotland's brown heath,
Twined with Ireland's green shamrock we see;
Then let 's bind them closer with loyalties free,
That 's the tricolour, Britain, for thee."

This was published in *Blackwood's Magazine*, and it is a very fair specimen of his power of versification.

Swinton's career at the University was one of success. In Professor Pillans' class the most distinguished part which he played was in some translations from Martial, for which he gained a prize. They were considered to show very great ability, and th family were kind enough to send me a copy of this exercise handsomely bound, which contains prefixed to it an autograph letter from Sir Walter Scott in the following terms:—

"My Dear Sir,—

"On my return from the country I found a prize exercise of translations from Martial from Mr Archibald, which I consider is my young friend whose progress I admired so much while under Mr Williams. I heartily give you joy of his proficiency, which I think displays command of both languages, and a fine taste besides. I hope, my dear friend, that the young gentleman will be a blessing to you and all his kin, which will ever give great satisfaction to yours, affectionately and sincerely,

"Walter Scott."

These translations are full of spirit, and exhibit much power of language and command over metrical composition. There are a few other versions contributed by Professor Aytoun, but on the whole the exercise speaks of proficiency in the elegancies of the Latin language, as well as in those of English verse. This was in the year 1829; he gained the medal in Professor Wilson's class in moral philosophy in 1831. The year 1830 he seems to have spent in attendance at Glasgow University, and there he distinguished himself not only in the classes, but in a debating club called the Athenæum; and at the close of that session a "*College Album*" was published, the contributors to which were students of the year, and among the rest were Archibald Campbell Tait, afterwards Archbishop of Canterbury; Mr Page Selfe, who became Police Magistrate in London; Swinton himself; and William Edmonston Aytoun, whom I have already mentioned. This little volume also is dedicated to Sir Walter Scott, and the copy before me contains an autograph

letter from Sir Walter addressed to Mr Campbell Swinton. He ends by saying:—

> "We are going to Abbotsford, and from thence to London, so can hardly hope to see you before summer, but will be then delighted to see you in the country. Believe me, with respectful thanks to you and your enterprising friends, very much your faithful and affectionate cousin,
>
> "WALTER SCOTT."

I have already mentioned the late Archbishop Tait, who studied at Glasgow and Oxford. He never attended the University of Edinburgh, although he became a member of the Classical Society. It had a summer session, and during that period Tait attended the meetings, and took an active part in its proceedings.

In 1831 Swinton became a member of the Speculative Society. His name appears in the volume entitled *The History of the Speculative Society*, on page 321; and it appears that the essays which he contributed during the session were on "Municipal Law and Moral Science," on the "State of European Politics at the Peace of Paris," on the "Causes which led to Buonaparte being declared Emperor of the French," and on the "Rise of the Middle Orders in England." In the course of his attendance at the Speculative he had occasion, of which he availed himself, to become well-informed as to current as well as past historical and political questions. His companions there were, among others, the late Edward Horsman, M.P. for Stroud; David Mure, afterwards Lord Mure; James Craufurd, afterwards Lord Ardmillan; John Thomson Gordon, who became Sheriff of Edinburgh, a man of brilliant ability; and George Makgill of Kemback, whom I have already mentioned. The latter died early, but was one of the most accomplished of the circle.

At the Speculative, Swinton distinguished himself in a remarkable degree, and became a very finished speaker. His style of speaking was eminently calculated to be effective in a popular assembly, such as the House of Commons. His flow of well-chosen language was something phenomenal. The difficulties which beset most public speakers, and which many of them never overcome, of hesitancy, and want of readiness of expression and of choice of words, he never experienced. The only criticism which could be made upon his style was, that it was sometimes only too fluent—too unbroken;

but my own opinion is, that one session in the House of Commons would have placed him in the front rank both of debaters and of orators in that august and fastidious assembly. Any redundancy and copiousness of expression would have been checked and chastened by the controversial and critical nature of the assembly itself, and his large and extensive knowledge of affairs and fund of cultivated intelligence would, I am satisfied, have raised him to great distinction. He joined the bar of Scotland as an advocate in 1833.

I should before have mentioned that for several years he had been in the habit, during the recess, of travelling, at first with a tutor through the Highlands, and in 1828 and 1829 he took tours on the Continent, visiting various places now familiar to tourists, but which at that time were not so easily accessible as they have since become. He went one year to France, another to Switzerland, and another to Italy, and in many instances revisited the same scenes. In 1828 he had the great advantage of travelling under the superintendence of the late Bishop Terrot, himself an accomplished scholar and a man of high intellectual attainments and thought. Professor Aytoun was, in the earlier of these tours, his travelling companion. Swinton continued these Continental wanderings in many after years, and recounted his progress in journals written at the time.

I may mention in passing that Swinton's time was not altogether consumed either in the study of law or in politics. He was a principal promoter of a Charade Company, composed of his own companions and intimates, who played with great acceptance and success in various Edinburgh circles. Of these the late Cosmo Innes was the principal manager, and Lord Neaves and Angus Fletcher of Dunans and Henry Jardine, son of Sir Henry Jardine, as well as Aytoun and Swinton, were principal performers. I find that in the diary which he kept some of these performances are noted from time to time—one in particular, I remember, which was acted at his father's house in Inverleith Place—a dramatised version of *Nicholas Nickleby*, in which William Aytoun sustained the part, first, of "Squeers," which he rendered admirably, and, secondly, of the "Infant Phenomenon," in which his attire created an intense sensation among the ladies of the audience.

From 1833 down to 1862 Swinton devoted himself with great

energy and fair success to his profession. He used to go to the circuit at Glasgow, and was engaged in several criminal trials of importance; and before he had been two years at the Bar he rendered a great service to the profession in initiating a system of Reports of Criminal Trials. This department of law reporting had fallen into decay, and, in fact, had not been systematically pursued for many years before. These reports continued under his superintendence for several years, and those which are published periodically now are substantially a continuation of the original work. I look upon this achievement as a very great boon to the science of criminal law; and if he had done nothing else in his career, Swinton would have deserved to be honoured and remembered in the profession. He continued to conduct these reports down to the end of 1841. He also edited and published separate reports of two celebrated criminal trials before the High Court of Justiciary—that of the Cotton-spinners in 1839, who were tried for conspiracy, and of the Claimant of the Stirling peerage, in 1839.

He had many qualifications for his profession, even apart from his great power of eloquence and reasoning. He had great assiduity, was rapid in his conceptions, had a clear brain, and a lucid power of expression, and, in short, had the prospect, at this time, of rising to distinction as a pleader. Fate, however, I do not say maliciously, but unfortunately for his opportunities of practice, interposed two obstacles. The first was that in 1842, on a vacancy occurring in the Civil Law professorship in the University, he was induced to offer himself as a candidate, and was successful. From 1842 to 1862 he held that important office, coming to it at a very early age. I believe that a more efficient professor never sat in a legal Chair; and the many brilliant pupils who came from his class to practise at the Bar, remembered with uniform satisfaction the clear, lucid, powerful expositions which they heard from him in his lectures. It is not easy to be an effective professor of law. The subject is one so entirely different from anything to which the audience have been accustomed in their previous studies, that a professor must sympathise very thoroughly with the prevalent cast of thought on the part of the students, before he can command their attention on such a theme. In this Mr Campbell Swinton was more successful than most; but, then, professorships

and practice seldom have walked hand in hand. For Themis resents the divided allegiance. She is an inexorable mistress; and unless her votary feels that she is all in all to him, rarely bestows her favours. In other and plainer words, a man seldom succeeds in rising to important practice at the Bar if he has anything else to do.

A second obstacle—not one to be regretted certainly, but still tending in the same direction—interposed itself before long. The estate of Kimmerghame, of which I have already spoken, came into market in 1846, and was purchased by his aunt, Miss Campbell of Blythswood, who, I think, was a sister of his grandmother. Miss Campbell had indicated her intention to Campbell Swinton's father, Mr John Swinton, of settling this old family property upon himself and his son. She died in 1850, and Mr John Swinton consequently succeeded to the estate. This, as I have said, formed another obstacle, or distraction at any rate, in the progress of his legal practice, for a man cannot be both a country gentleman and a lawyer in large practice—at least if he resides on his property and does his duty to his people. There are exceptions, of course, to this, but there is no doubt that an independent income from landed estate is not in favour of an advocate obtaining a large share of practice at the Bar.

From 1850 to 1860 this estate of Kimmerghame occupied a good deal of such opportunities as he had of leaving Edinburgh. Being now independent, or with the prospect of independence in his circumstances, he began to think of entering Parliament, and in 1852 he contested the Haddington burghs against Sir Henry Ferguson Davie, but without success. In the meantime a new house had been planned and was in course of erection on the estate of Kimmerghame, and this was a subject of great interest, and occupied a considerable portion of his attention. I find that in his diary he notes in 1856 that he has spent a great deal of time at Kimmerghame in the course of that year. It was unfortunate for Swinton himself, and for his reputation as an orator and a politician, that the Conservative party were at that time little in favour in the Scottish constituencies. For my own part, I have always regretted exceedingly that the House of Commons had not had the benefit of so energetic, so thoroughly equipped, and so able a member, because he added to very large acquirements in point of literature a thorough

knowledge of legal principle, and a thorough acquaintance with the wants of the rural population. When the Government of Lord Palmerston was turned out in 1858, I find a memorandum in his diary to the effect that he had been employed to go to London to help Charles Baillie in carrying a Reform Bill. Charles Baillie was the Lord Advocate under Lord Derby's Government of that year, and Swinton makes a notandum in his diary with the melancholy remark that this was rather against his conscience. However, the Government were defeated, and Lord Palmerston's Cabinet of 1860 lasted for many years.

Notwithstanding his early inroads into periodical literature, I have not been able to trace Mr Swinton's pen in later life in the current publications of the day, excepting in one instance. By the courtesy of Messrs Blackwood I have been furnished with a copy of the number of their *Magazine* in which the only article contributed by Swinton appears. It is dated February 1837, and is entitled "A Word in Season to Scottish Conservatives." It is a good, hearty all-round challenge of all Whig doings and of all their ways. It is not sparing of large words and strong opinions. It says, "The Whigs were not four years in office without affording proof enough that if grasping nepotism, open violation of the most solemn pledges, and selfish clinging to place at whatever sacrifice, are the characteristics of any political party, they are not exclusively at least the qualities of the Conservatives." But the perfervid strain of this performance, which is sustained and vigorous throughout, had, like most things a possible history. Sir Robert Peel had been elected Lord Rector of Glasgow University in January 1837. He was entertained to dinner by the citizens of Glasgow, and delivered a great oration on the 12th of January. He was the guest of Blythswood during his stay at Glasgow, and rumour had it that Swinton was during that period at the service of the great statesman as temporary private secretary. From his family connection with Blythswood I think the legend is probable, and the intense ardour of the *Blackwood* article to a certain extent corroborates this view. But certainly I never heard him speak on the subject, although we were much together at that time, and probably if the rumour was true, the relations which he held to the great statesman were too confidential to be made the subject of gossip.

In nearing the end of his academic career I may mention one duty for which Swinton was almost uniformly selected by the Senatus Academicus, that of presenting the candidates for graduation. This was a task difficult and indeed irksome to most, for to speak of a number of men in succession without tautology and without confusion is not given to all. But Swinton's ready inspiration was always equal to the task. During his time Mr Gladstone was elected Lord Rector, and Lord Brougham Chancellor of Edinburgh University in 1860, and he took part as usual in their installation. But the happy turns of expression, and the genial spirit in which he uniformly performed this task, whether the candidate agreed or did not agree with his opinions, were the theme of universal admiration, and I never knew him fail.

1862 was the last year in which he retained his position as professor. The estate of Kimmerghame, with the new house, made demands upon his time and presence which he found incompatible with continuing his exertions in his class, and consequently thus ended his career at the Bar. For the rest he was simply an intelligent, cultivated, and hardworking country gentleman. But before his departure he had the satisfaction of having a tribute paid to him by which he was not unnaturally greatly gratified, and which of its kind was, if not unprecedented, at least unusual. In view of his approaching resignation of his Chair and departure from his residence in Edinburgh, a number of his friends invited him to a semi-public dinner. Sir William Stirling-Maxwell of Keir presided, and Sir William Gibson-Craig was the croupier. There were present men of all opinions and of all political proclivities: several judges—including the Lord Justice-General and the Lord Justice-Clerk, Lords Curriehill, Ardmillan, Neaves, Jerviswoode, and Ormidale; Sir Hugh Campbell, Sir David Dundas, Sir John Marjoribanks, Mr Campbell of Blythswood, Mr David Mure, M.P., and a long list in addition. I have been allowed to consult a little volume containing not only the announcement of the dinner and a copy of the *menu* and of the toasts, but a variety of private letters which the family received on the subject afterwards, expressive of the satisfaction with which the writers had regarded the proceedings of the evening. I shall not quote from these, but I had the pleasure of being present myself, and I can only say that the tribute was a

most flattering one to Swinton, and was exceedingly gratifying to his friends. One feature of the evening's proceedings was a song written for the occasion by Lord Neaves, of which I shall simply quote one stanza as expressive of its general character and bearing. The second stanza runs thus:—

> "He doffs the gown, he quits the town,
> His ancient haunts he leaves;
> Henceforth his sphere will be to rear
> Good mutton and fat beeves,
> To sow and reap, to sell or keep
> His wheat or barley sheaves,
> While, sad and slow, his comrades go
> Lamenting, with Lord Neaves,
> That he's a country gentleman
> All of the present time."

And so from 1862 to 1890 he remained in great reputation and honour, a country gentleman living on his own property and among his own people, consulted by all and sundry, gentle and simple, whom his versatility and kindliness attracted, and seldom or never in vain. His father died in the year 1867, but of course the great proportion of the labour which the estate implied had before fallen upon the shoulders of Swinton. In his capacity of a country squire he filled almost every position in local management which was open to him. His knowledge, quickness of apprehension, and urbanity of manner caused him to be consulted from all quarters upon all manner of subjects. As I have already said, he combined knowledge of country affairs with an amount of legal lore very seldom combined with rustic pursuits. It would be impossible for me to enumerate in detail the amount of willing work which he performed in that capacity. He continued to be a member of the General Assembly, was much in the confidence of the clergy, and devoted a considerable portion of his time to the discharge of these duties. He was a member of the School Boards when they were first introduced, and indeed few of the parochial or county institutions were without his assistance. He continued, as he had done during the greater part of his life, to act as a Director of the Edinburgh Academy, his zeal for, and devotion to which had suffered no diminution.

I have been furnished with memoranda from his diaries, which

he kept with considerable regularity down to the last years of his life, but there are no salient features of which I could take advantage in such a notice as this. One only I would mention, and that is the marvellous sweetness, kindliness, and generosity of the whole of these private notanda, as well as the reverential tone of his thoughts. Keen as he could be, and ardent in the pursuit of any principle to which he was attached—a man who never feared to speak his mind, and generelly had a very decided mind to speak—there is not a tinge of acerbity to be found in him; nothing but good fellowship and just appreciation, even of his opponents. I have been very much touched by that feature in his diary. Even when politics ran highest, there was not a drop of personal bitterness. The subjoined list, with which I have been favoured, shows the extent of his public avocations:—

Offices in Connection with County Business.

A Commissioner of Supply in 1849—for the earliest entry in the Minute-Books of the County of his being present at a meeting of Commissioners of Supply is at the meeting held in October 1850.

Justice of the Peace, probably the same year, but no record exists of such appointment.

Chairman of Committee appointed to carry out Commissioners of Supply Act, 1857.

Chairman of Lands Valuation Committee, 1854.

Chairman of Standing Committee of Middle District of Turnpike Roads in Berwickshire, 1862, on resignation of his father, John Swinton. Continued in this office until adoption of Roads and Bridges Act.

First Chairman of Middle District Road Trustees under Roads and Bridges Act, 1882.

Chairman of Police Committee of the County in 1871.

Deputy-Lieutenant, 1874 (Duke of Roxburghe, Lord Lieutenant).

Chairman of Local Authority under the Contagious Diseases (Animals) Act, 1879.

Member of Prison Board.

Member of Income-Tax Commissioners.

These bodies have no stated Chairman, but, when present, Mr Swinton was usually appointed Chairman.

(Mr Deas, writer, Duns, and at one time Clerk of the Peace, in sending list of above offices, remarks:—"He continued to attend nearly every meeting of all these bodies from the commencement until his retirement in 1883 and 1884.")

For many years Vice-Chairman, and afterwards Chairman, of the Parochial (Edrom) Board, and Chairman of the School Board of Edrom.

For thirty-five years Representative Elder to the General Assembly from the

Presbytery of Duns; resigned on account of health in 1884, having been unable to attend the Assembly during session of 1883.

Border Counties Association.—Was one of the original members; elected a Vice-President when Association formed in 1865; elected President in 1872 on retirement of Lord Jerviswoode; resigned this office on account of health in 1884, and was then appointed one of the Patrons.

Berwickshire Naturalists' Club.—Became a member in 1861; elected President for the year in 1876.

Ellem Fishing Club.—Admitted member in 1838; Preses in the years 1858, 1859, and 1860.

Member of the Board of Manufactures, Scotland, for nearly twenty years, resigning January 1888.

Director, Bank of Scotland, 1864–1888.

Connection with University Court, Edinburgh (see Minute, November 21, 1887). Professor of Civil Law, 1842–1862; and since then as Assessor to two successive Rectors for six years, as Chancellor's Assessor for five years, and as a Member of the Court of Curators for six years.

"Long and intimate relation" with the Highland and Agricultural Society of Scotland, Convener of Committee of District Shows, Director, Member of Council on Agricultural Education, and also of Veterinary and other Committees.

It would seem from his journals of his travels abroad that for some of his earlier years he was not in strong health; but still he must have had a vigorous constitution, for he died in his 78th year. Down to 1883, when he had passed the age of 70, apparently his activity and strength had known no diminution. In that year he had a sudden seizure, which next morning medical men pronounced to be of a paralytic nature. It was not severe. I saw him the year after, and found him in very good spirits, and regaining his power of locomotion. He continued to improve till 1886, when unfortunately he met with a severe carriage accident, in which his coachman was killed, and he himself so injured that he never recovered his power of locomotion. He remained, however, fully alive to all that was going on round him, taking great interest both in the past and in the present. The end came unexpectedly, and he died on the 27th of November of last year.

So ends my tale. It has been a mournful, but to me a very pleasant task, to recall the life of one with whom I was so intimate, and with whom, although we differed on almost all public questions, I retained the most friendly, amicable, and confidential relations to the end. He was a friend worth cultivating, for he took an interest in everything that was intelligent and refined; a master himself of

most intellectual pursuits, he had less of pedantry than any man I ever knew. Always ready to rejoice with those that rejoiced, and to laugh with those that laughed.

I feel very grateful to the Society for allowing me this opportunity of relieving the overflow of my very sincere affection, regard, and regret.

One word of postscript in regard to his domestic relations. He married, in 1845, Katherine Margaret, third daughter of Sir John Pringle of Stitchill, Bart. She died in 1846, leaving a daughter, Katherine Margaret. In 1856 he married, secondly, Georgina Caroline, third daughter of the late Sir George Sitwell of Renishaw, Bart. Her mother was a sister of the late Archbishop Tait. By the last marriage were born three sons and a daughter, all of whom, with their mother and the daughter of the first marriage, survive.

James Leslie, Civil Engineer.

(Read January 19, 1891.)

Mr Leslie was born at Largo, Fifeshire, in 1801, and was the son of Alexander Leslie, Architect and Builder there.

After receiving part of his education at the Parish Schools of Largo and Newburn, and afterwards at Mackay's Academy, Edinburgh, he attended the Edinburgh University for three years, his uncle, afterwards Sir John Leslie, being then Professor of Mathematics there. In 1818 he was apprenticed to Mr W. H. Playfair, the well-known architect, who was at that time engaged in the erection of the Edinburgh University buildings, and remained with him till 1824. Although Mr Leslie did not follow up the profession of an architect, his early training in this line enabled him from time to time to furnish with acceptance designs for public buildings, the most important of which are the Custom House at Dundee and Wood's Hospital at Largo.

Mr Leslie early turned his attention to engineering, and in 1824 he was taken into the office of Messrs G. & J. Rennie, Civil Engineers, London, with whom he remained about four years. During that time he was engaged at the building of London Bridge and also the bridge over the Serpentine in Hyde Park, and also with works in connection with Sheerness Docks, Plymouth Breakwater, the West India Docks, and other extensive and important works.

In 1828 Mr Leslie was appointed by the Leith Dock and Harbour Commissioners Clerk of Works to carry out, under the direction of Mr Chapman, C.E., Newcastle, the extension of the East Pier of Leith, and he was subsequently employed by the Navy Board to superintend the construction of the West Breakwater there, also designed by Mr Chapman.

In 1832 he was appointed Resident Engineer for the Dundee Harbour Works, and almost simultaneously he was elected to a similar post at Sunderland, which of course he could not accept. He remained at Dundee till 1846, and while there, along with many other important works, he carried out the construction of the Earl Grey's Dock from the designs of Mr John Gibb of Aberdeen.

While at Dundee Mr Leslie carried out a further extension of the East Pier of Leith, and designed and executed the Wet Dock at Montrose and Harbour Works at Arbroath, Kirkcaldy, and various other places. He also constructed locks for the Monkland Canal, Glasgow, and built a handsome bridge across the River Leven in Fife.

In conjunction with Mr Jardine, the engineer of the Edinburgh Water Works, he in 1836 prepared the first water scheme for supplying Dundee from the Monikie District.

In 1846 Mr Leslie removed to Edinburgh, and shortly after that he succeeded Mr Jardine as engineer to the Edinburgh Water Company. In 1849–50 he designed and carried out a plan for taking empty boats afloat up an inclined plane at Blackhill, for the Monkland Canal, Glasgow, thereby saving both time, labour, and much water, as compared with the usual method of lockage. In 1852 Mr Leslie, in connection with Mr J. M. Rendel and Mr Mackain, was engineer for a scheme for supplying Glasgow with water from Loch Lubnaig, for the Glasgow Water Company. This scheme, however, did not pass, having been keenly opposed by the Corporation of Glasgow, who shortly after that took over the control of the Water Works from the Company.

The first of the more important works carried out by Mr Leslie, after his appointment as engineer to the Edinburgh Water Company, was the construction of the Torduff, Clubbiedean, Bonally, and Loganlea Reservoirs, and the heightening of the embankment of the Glencorse Reservoir.

In 1856, under Mr Leslie's care, the Bill for appropriating the Colzium Springs was carried through Parliament, and under its provisions the Harperrig Reservoir, for providing compensation to the Water of Leith, was constructed; and in 1863 a further supply was introduced under his superintendence from the Crosswood Springs.

In 1870, when the Corporation of Edinburgh took over the business of the Water Company, the newly-constituted Water Trust elected Mr Leslie consulting engineer, and at the same time appointed Mr J. W. Stewart resident engineer. Mr Leslie was instructed to report on all the available sources of additional supply for the city, which had already been reported on by Mr Stewart,

and the Trustees having received this report, again adopted the St Mary's Loch Scheme, which had previously been thrown out on Standing Orders in 1869, and again instructed Mr Stewart to prepare the necessary plans for Parliament. Differing from Mr Stewart as to the probable cost, Mr Leslie refused to allow his name to appear as engineer of the scheme; and after having been keenly fought in both Houses of Parliament, the St Mary's Loch Scheme was rejected by the Committee of the House of Lords.

After the next municipal elections, Mr Leslie was appointed sole engineer of the Water Trust, and in 1873 he, along with Mr Thomas Hawksley, C.E., London, was instructed to report as to the best means of obtaining additional supplies for Edinburgh. They issued a joint report, recommending that the necessary additional supplies for the city should be obtained from the Moorfoot Hills, and this scheme having been approved of by a plebiscitum of the citizens, the Bill was passed by Parliament during the following year, and under it an additional supply of over eight million gallons per day was obtained.

Mr Leslie was also engineer of the Lintrathen Water Scheme, by which Dundee obtained an additional supply of eight million gallons per day. He was connected with the improvement works of most of the towns of Scotland, and acted in conjunction with his partners as engineer for the Water Supply of Paisley, Berwick-on-Tweed, Dunbar, Peterhead, Galashiels, and many other important places. He was also engineer for various harbour works, including those of Easdale, Stranraer, and West Wemyss.

Mr Leslie had a reputation as an engineer which was not confined to this country, his advice having been sought in regard to extensive reclamation works at Bilbao, in Spain, and also as to the construction of floating docks at Cadiz. He was also consulted by the Indian Government as to the improvement of the navigation of the River Godavery by means of inclined planes, on the principle formerly adopted by him on the Monkland Canal.

In 1862 Mr Leslie was appointed by the Home Office, along with Messrs W. Ffennell and Frederick Eden, a Scottish Salmon Fishery Commissioner, an office which he held until the institution of the present Scottish Fishery Board in 1882. The duties of the Commissioners were to fix the boundaries of the districts of every salmon river

in Scotland, the divisions between the upper and lower proprietors, and the limits of the various estuaries, and also to frame bye-laws for the regulation of the fisheries. Much of this work was not only difficult, but involved no small amount of fatigue, and even hardship, the greater part of it having to be executed in winter, and in great haste, and often in very inaccessible districts, and without the assistance of reliable maps. Mr Leslie's sound knowledge on all engineering matters, and his acknowledged integrity, led to his being frequently employed as an arbitrator in important cases of dispute, both in Scotland and elsewhere.

About the time of the "Railway Mania" Mr Leslie was a good deal engaged in this line of business, and although he was engineer for several projected schemes, he never followed it up, but preferred to remain associated with water and harbour works.

Mr Leslie was a man of very vigorous constitution, and until he had the misfortune to break his leg by a carriage accident, which occurred about ten years before his death, he was capable of enduring great fatigue. He continued engineer to the Edinburgh Water Trust until his death, he having in 1870 associated with himself in partnership his son, Alexander Leslie, and shortly afterwards his son-in-law, Mr R. C. Reid.

Mr Leslie was connected with the Institution of Civil Engineers, London, for more than half a century, having been admitted as a member in 1833. He was elected a fellow of this Society in 1858, and he also belonged to various other learned societies in Edinburgh and elsewhere, including the Meteorological Society of Scotland, in which he continued to the last to take a deep interest.

A man of generous disposition, Mr Leslie was a liberal subscriber to every public purpose that approved itself to him, and he gave largely to charitable institutions and also to private wants.

In spite of his serious accident, he continued daily to take exercise, though with much difficulty. He was, however, entirely confined to bed for the last six months of his life, and endured no small amount of suffering, which he bore with patience and even cheerfulness. He died on the 29th of December 1889, in the 89th year of his age.

Professor Cosmo Innes Burton.

By William Marshall, Esq.

(Read July 20, 1891.)

By the death of Cosmo Innes Burton the Society has lost one of the most promising of its younger Fellows. His loss is keenly felt, not only among his large circle of friends, but by many who, though they did not know him personally, had come under his influence as a teacher, and had learned his worth. The following short sketch of his life will show better than anything else the untiring energy, perseverance, and devotion to science by which he was characterised:—

Mr Burton was born in 1862, and was the younger son of John Hill Burton, the well-known historian, from whom he inherited much of his originality of thought and dry humour. He began the study of science in 1879, attending the classes necessary for the Science Degree in the University of Edinburgh, where he graduated as Bachelor of Science in 1884. During his University course he distinguished himself by winning the Neil-Arnott Prize in Physics in 1881, and the Hope Prize in Chemistry in 1885. The winter of 1882–83 was spent in Munich, where he studied under Professor Eslenmeyer. From Munich he went to Paris, where for nine months he worked in the laboratories of Professor Wurtz. While there he assisted the late Professor Henninger in his researches on Erythrite, and Professor Hanriot in his investigations on Strychnine and the Compounds of Glycerine.

In 1885 Mr Burton received the appointment of Assistant to Professor Japp, F.R.S., at the Normal School of Science, London, with whom he published jointly several papers, which appeared in the *Proceedings of the Chemical Society.*

About this time the Town Council of Edinburgh was making an inquiry into the state of ventilation in the Board Schools and Public Buildings in the city, and Mr Burton was asked to undertake the analysis of the air in connection with this investigation. The

results of his extensive and elaborate series of observations are published in the Minutes of the Town Council for 1888.

During the winters of 1888-89 he acted as Class Assistant to Professor Purdie of the University of St Andrews, and at the same time made some experiments on the presence of iodine in sea-water.

The University Extension Scheme found in Mr Burton one of its most ardent and hard-working supporters; and the numerous courses of lectures he gave in various places were sufficient proof that his support was of a most practical nature. It was while engaged in this work that he received the appointment of Professor of Chemistry in the Technical School of Shanghai—a post which was quite after his own mind. There he felt he would be untrammelled by traditions or examination regulations, and could test in practice his ideas and theories regarding the teaching of science. Full of hope and enthusiasm, he went out with his young wife in the early summer of last year, only to be struck down by a short and fatal illness three months after his arrival, and just as he was about to start his work, and everything seemed to point to a bright and prosperous future. He died of malignant smallpox on the 31st of October 1890.

Mr Burton's tendencies had always been in a scientific direction, but he had no great liking for conventional methods and programmes in the teaching of science. He had a rooted dislike to empiricism, preferring to generalise rather than to particularise, which tendency was clearly observable in his work. His style of expression was terse and clear, and this, along with his skill in experiment, made him an attractive lecturer. He was nothing if not practical. He had a strong sympathy with the working classes, and conducted a most successful course of lectures to working men in Edinburgh. Shortly before leaving for China he was engaged, in conjunction with his friend Mr Marshall, in a research on the effects of compression on solids and liquids, the results of which were embodied in a paper recently read before the Royal Society of London.

This brief summary may suffice to show what we have lost as a scientist—a man thorough in all that he did, full of ideas argued out on a sound basis, and, above all, devoted to his work. At the

very outset, a career which promised so much has been cut off. What we have lost as a friend not a few are but too well aware, and it is not so easy to tell. Little did we think when we said good-bye to him on his departure for China that we had bidden farewell for ever to one who was the best of comrades and truest of friends.

INDEX.

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6

PROCEEDINGS

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SESSION 1890–91.

CONTENTS.

I

N

C